Phase A Study for a Multi-User Facility for Exobiology Research

ESTEC CONTRACT N° 13678/99/NL/JS

EXECUTIVE SUMMARY

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TABLE OF CONTENTS

1. INTRODUCTION

The Exobiology Multi-user Facility (EMF) is devoted to the search of life on planetary surfaces, and more specifically on Mars.

EMF has been conceived as a multi-user facility providing in a modular way:

- A Sample Acquisition, Processing and Handling System.
- A set of Analytical instruments.
- A Service Module for physical and operational support.

The mission of EMF is innovative and challenging, both for its scope (the search of extraterrestrial life) and the *in-situ* chemical and physical analyses in a very constraining environment (the Mars surface). At the end of present project (phase A study), the EMF design can be considered sufficiently consolidated to ensure its feasibility with full satisfaction of the key science objectives although the technical and resource constraints imposed by the selected mission scenario(s) could be limiting in some cases.

The presented architectural design of the EMF fulfils the requirement, ma we cannot exclude the possibility to improve it, as a deeper knowledge of the scenario and the possible instruments will be available in the following steps of the project.

The study has covered the following main topics:

- Mission assessment, with the objective to identify a possible scenario for EMF mission
- Architectural Design of EMF
- Planetary Protection, Cross Contamination and Organics Pollution Issues
- Drill S/S Definition
- Sample Preparation and Handling S/S Definition
- Instruments Definition

1.1. Scope

Present document is the Executive Summary of EMF System. The main achievement from the activities carried out along the study by the Team led by Officine Galileo are summarised in this document, as well as the envisaged concern areas.

Chapter 2 reports the outcome of Mars Mission survey; Planetary Protection and Pollution issues are reported in chapter 3; EMF conceptual and architectural design is outlined in chapter 4. Chapter 5 addresses the Sample Acquisition subsystem, while the Sample Preparation & Handling S/S characteristics are summarised in chapter 6. The Scientific Instruments are illustrated in chapter 7. The budgets of the overall EMF are reported in chapter 8.

1.2. Officine Galileo Team

The work in present project has been carried out by a Team composed by:

- ALENIA DIFESA, Officine Galileo Space Business Unit, with the role of Prime Contractor and the technical responsibility for the optical instruments and the service module.
- TECNOSPAZIO, with the responsibility of the drill and the sample/preparation subsystems.
- ASTRIUM, formerly DASA-Dornier Raumfahrt-Infrastruktur, Friedrichshafen, responsible of the chemical and physical investigation instruments.

Experts in the field of planetary science, Mineralogy and Chemical Analyses have supported the Industrial Team:

- Prof. G.G. ORI (IRSPS-Pescara, and University of Bologna)
- Dr. Lucia MARINANGELI (IRSPS, Pescara)
- Dr. J. WAGNER (University of Jena)
- Prof. Wänke, Dr. Rieder (Max-Planck-Institute, Mainz)
- Dr. Angioletta CORADINI (Istituto di Astrofisica Spaziale, IAS – CNR, Rome)
- Dr. R. OROSEI (Istituto di Astrofisica Spaziale, IAS – CNR, Rome)

Moreover we acknowledge the fruitful discussions on Raman analysis with Prof. E. M. CASTELLUCCI and Dr. M. BECUCCI (LENS, University of Florence), and the technical contribution from Dr. A. DEL BIANCO (CTR, Austria)

1.3. Study Logic

The Study work was conceptually divided in two sequential phases:

- ***Phase I:*** Scientific Requirements vs. Technology Revision Phase, where the key technological assumptions performed during the Science Team Study was reviewed on the base of a careful integration between science issues and good space engineering practice available at industry.
- ***Phase II:*** Conceptual Design Phase, where, starting from a confirmed set of scientific requirements the Exobiology Multi-user Facility conceptual design was developed up to the level of a phase A study.

Although the process is by nature an iterative one, nevertheless from the development logic point of view the two phases represented the expected evolution of the study activities, initially (Phase I) characterised by a strong integration between scientific and engineering issues, and subsequently (Phase II), more oriented to engineering aspects.

The logic flow of the study activities is represented in Fig.1.3-1.

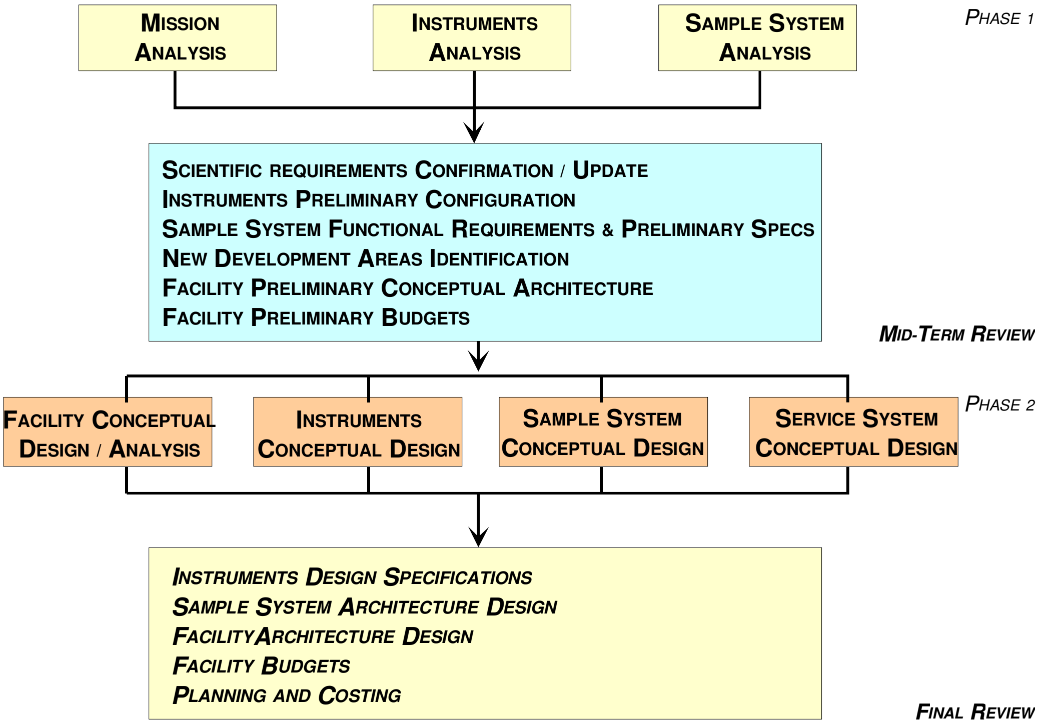


Fig.1.3-1 Study Logic

1.4. Applicable Documents

AD1 Statement of Work of "Phase A Study of a Multi-User Facility for Exobiology Research", Gs-578.98.SOW

AD2 ESA EXOBIOLOGY Science Team Study on THE SEARCH FOR LIFE ON MARS, Final Report, June 1998.

AD3 EXOBIOLOGY IN THE SOLAR SYSTEM & THE SEARCH FOR LIFE ON MARS, Report from the ESA Exobiology Team Study 1997-1998, SP-1231, October 1999.

2. MARS MISSION ANALYSIS

A review of past and future missions tom Mars has been carried out with the purpose to outline the typically expected constraints. More in detail, the NASA Mars Sample Return missions, formerly scheduled in 2003 and 2005, was taken as reference.

Here we summarise the most important constraints that were identified. These boundary conditions were used in the definition of EMF payload.

A sketch of the NASA '03/'05 Lander is shown in Fig.2-1.

The allotted volumes for Additional Payload, that could be the EMF Sample Preparation and Handling, and the Instrument Package, are indicated in Fig.2-2.

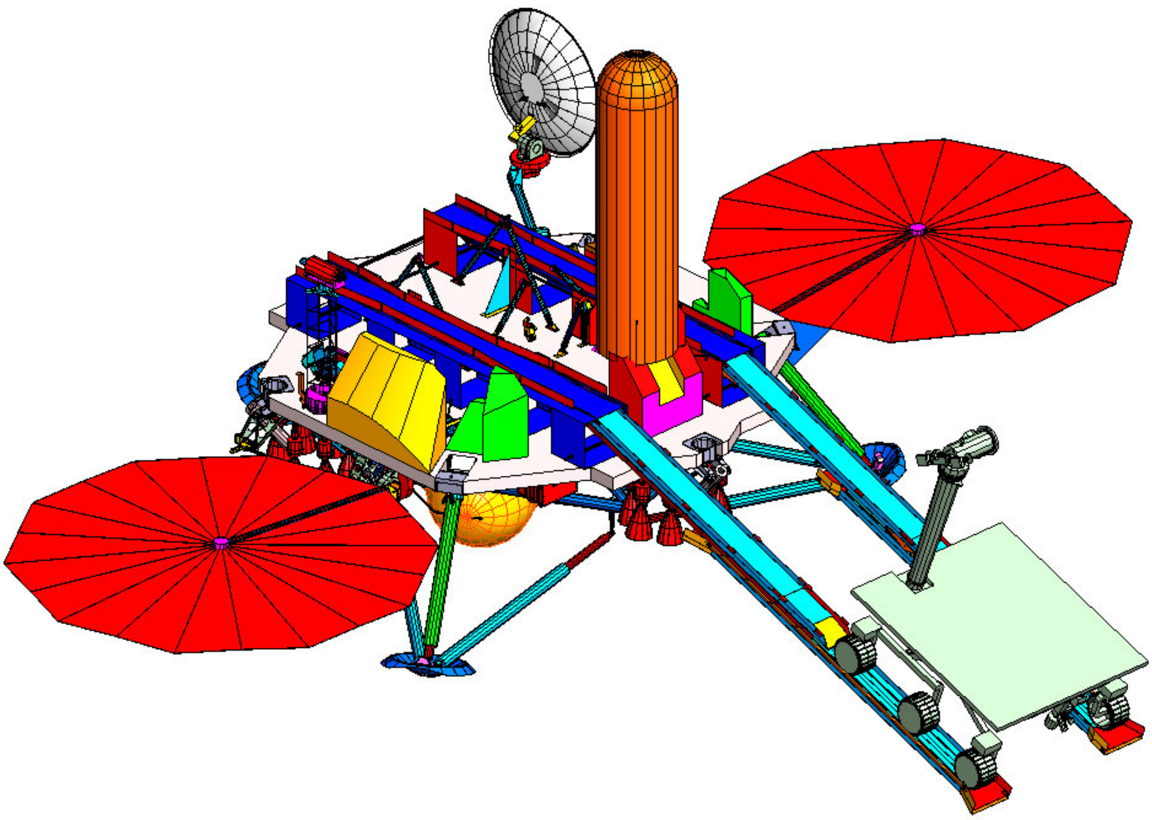


Fig.2-1 Lander with Rover & MAV deployed and Additional Payload areas depicted, (note: worst case height of instrument deck is ≈1.7 m above the planet surface)

The Fig.2-3 shows the stowed configuration of Lander, demonstrating the tight volume constraints that are imposed to equipment placed on the deck.

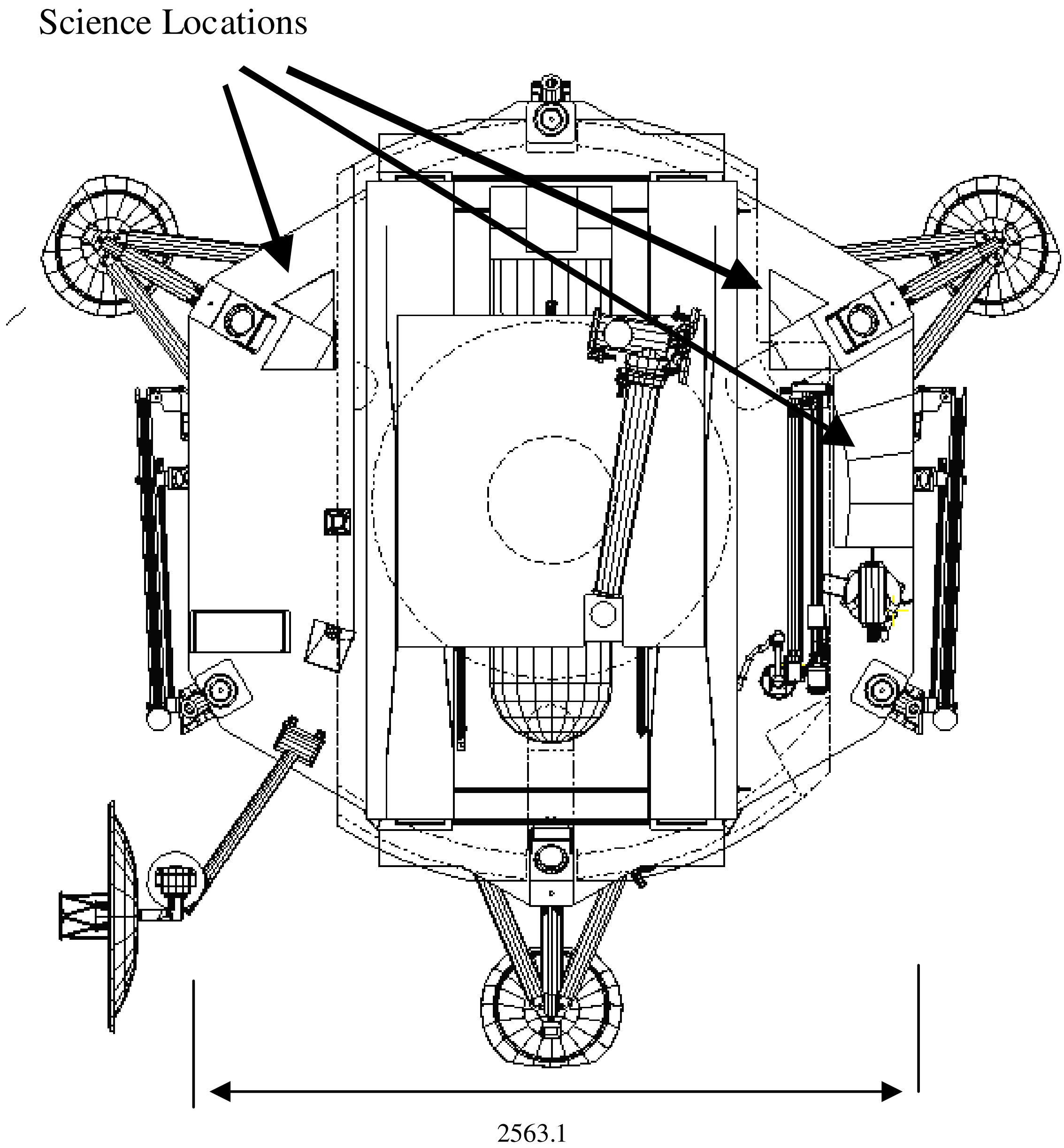


Fig. 2-2 Instrument Deck Plan Views

The summary of allotted resources for Additional Payload in NASA '03/'05 missions is reported in Tab.2-1.

The environmental conditions, both during cruise and Mars operations, are expected very harsh; the environment is described in Tab.2-2.

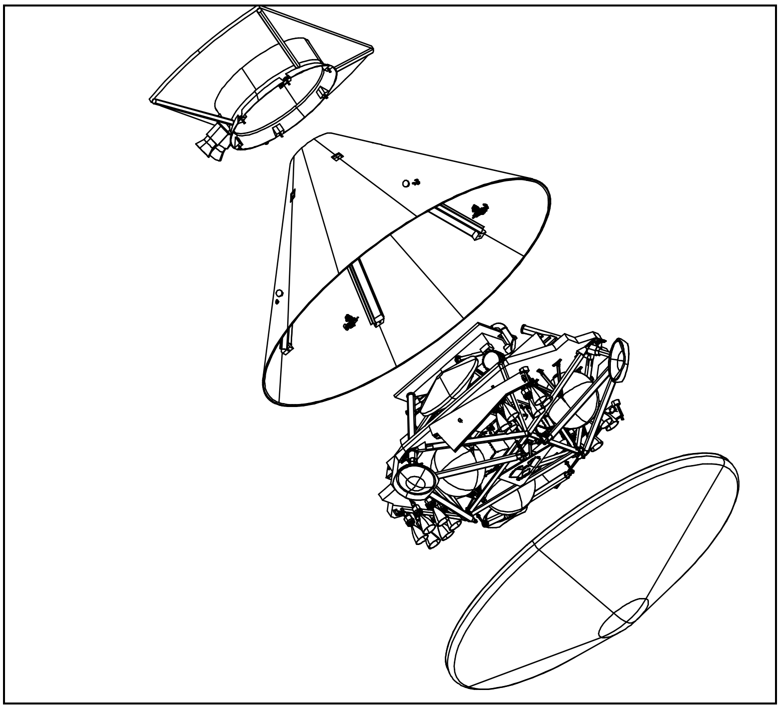


Fig.2-3 Exploded View of lander, Cruise Stage & Aeroshell

Mass	< 50 kg	
Size	P/L Locations	Volume (dm³)
	+Y AP Envelope 1	56.40
	-Y AP Envelope 2	13.78
	-Y AP Envelope 3	13.78
Power	Peak Power	60 W
	Daytime Energy	350 W-hrs (before Sol 65) 150 W-hrs (after Sol 65)
	Night-time Energy	100 W-hrs
Data	10 Mbits per SOL of telemetry (CCSDS encoded packets) TOTAL: 100 Mbit before Sol 65 TOTAL: 50 Mbit after Sol 65	

Tab.2-1 Summary of allotted resources for AP's

Environment Temperatures	**Convective Environment**	**Radiative Environment**
Ground processing (TVAC)	(n/a)	-145 °C ÷ 50 °C
Ground processing (non-TVAC)	5 °C ÷ 50 °C	(n/a)
Pre-Launch (on the pad)	5 °C ÷ 30 °C	(n/a)
Post Launch fairing separation	(n/a)	5 °C ÷ 30 °C
Cruise to Mars	(n/a)	-135 °C ÷ -40 °C (aeroshell)
Surface Operations on Mars	-123 °C / 0 °C	-173 °C ÷ -128 °C (sky temp)
Sun Irradiance		
For optical depth of 0.0		
THERMAL RADIATION	Perihelion	Aphelion
Direct Solar:	710.0 W/m^2	490.0 W/m^2
Nominal Day - optical depth of 0.2		
THERMAL RADIATION	Perihelion	Aphelion
Direct Solar:	587.0 W/m^2	405.0 W/m^2

Tab.2-2 Summary of expected thermal environment

3. PLANETARY PROTECTION, CONTAMINATION, POLLUTION

The pollution and contamination problems are severe constrictions to the EMF architecture and overall design. The cleaning and sterilisation techniques, which in principle can solve this kind of problems, have a major impact on materials, electronics devices, machining quality level. This leads to an increasing of the costs of the facility so high that, ignoring this problems also at the very beginning of the project, vanishes the efforts to reduce costs using existing adapted diagnostic system and devices. The analysis of possible easy and cost effective sterilisation/cleaning procedures will be considered as one of the main task for each of the instruments, devices and subsystems during the study phase.

Basic requirements have been individuated for the Planetary Protection and Exobiology Experiments: the Forward Contamination Protection (Mars shall be kept clean of possible biological contamination from Earth); Back Contamination Protection (Earth shall be kept clean of possible biological contamination from Mars, in case of re-entry of samples).

These basic rules include the Experiment Contamination Protection, i.e. the samples shall be kept clean, in case of in-situ operation, of possible pollution/contamination due to Earth pollutant/contaminant residuals on the instruments and handling devices.

Moreover it must be considered that the automation of the facility also leads to a different kind of pollution, i.e. the one coming from the re-utilization of instruments and sample containers and the eventual dispersion of powder during the samples preparation.

The cleanness of this kind of facilities involves well-known technologies, applied during manufacturing, assembly and test of space items, especially when optics and electronics are involved. The cleanness shall be linked to an on line continue monitoring during all the phases of the instrument development.

The instrument self-cleaning and the contamination removing procedure are usually encountered in multi-user facility for Microgravity experiments in Life Science and Fluid Science. These problems are usually very relevant for experimental age sensitive substances (as water and water solutions) and manned flight. The experience that the Team has gained on this field can give the guideline on how to tackle the contamination removing related problems. Mainly four aspects of the contamination removing and control shall be addressed during the system development:

- contamination analysis and assessment of the acceptable cleanness levels with respect to both the performances of the instruments and the Planetary Protection requirements.
- The contamination agents detection and monitoring (i.e. biological techniques to detect culturable and non-culturable microorganisms, cells, and biological material). The monitoring and detection shall be used both on line during the final assembly of the facility and during the development tests to assess sterilisation methods and material compatibility.
- The cost-effective sterilisation and cleaning. Different sterilisation techniques (dry heat, wet heat, oxidant agents, u.v. radiation, ionising radiation, sterilising fluids etc.) will be analysed with respect to materials compatibility, assembly and tests philosophies, and general system architecture.
- The sealed containment, deployable biobarriers, aseptic transfer. These aspects are extremely important, especially for samples return mission. Moreover the sealed containment, the utilization of biological filter (e.g. HEPA or non-HEPA filters) and the problems of aseptic transfer of material or containers from inside to outside of EMF or *viceversa* are anyway to be considered in the design of the facility.

4. EMF SYSTEM

In this chapter the definition of the EMF conceptual and architectural design is provided, on the basis of assumed mission scenario (baseline: NASA Mars Sample Return 2003/2005).

The functional configuration of EMF includes three main systems: the instruments Package; the Sample Acquisition, Preparation and Handling System; the Service System.

The EMF installed on the Lander has the capability to acquire Mars samples (to a depth up to 1.5 m requirement, 5 m goal and at a distance from the Lander in the range 0÷0.5 m), prepare and analyse them autonomously.

4.1. EMF description

Scope of EMF is to carry out *in situ* science through optical, chemical and physical investigations.

The main elements composing EMF can be found in the hardware tree depicted in Fig.4.1-1.

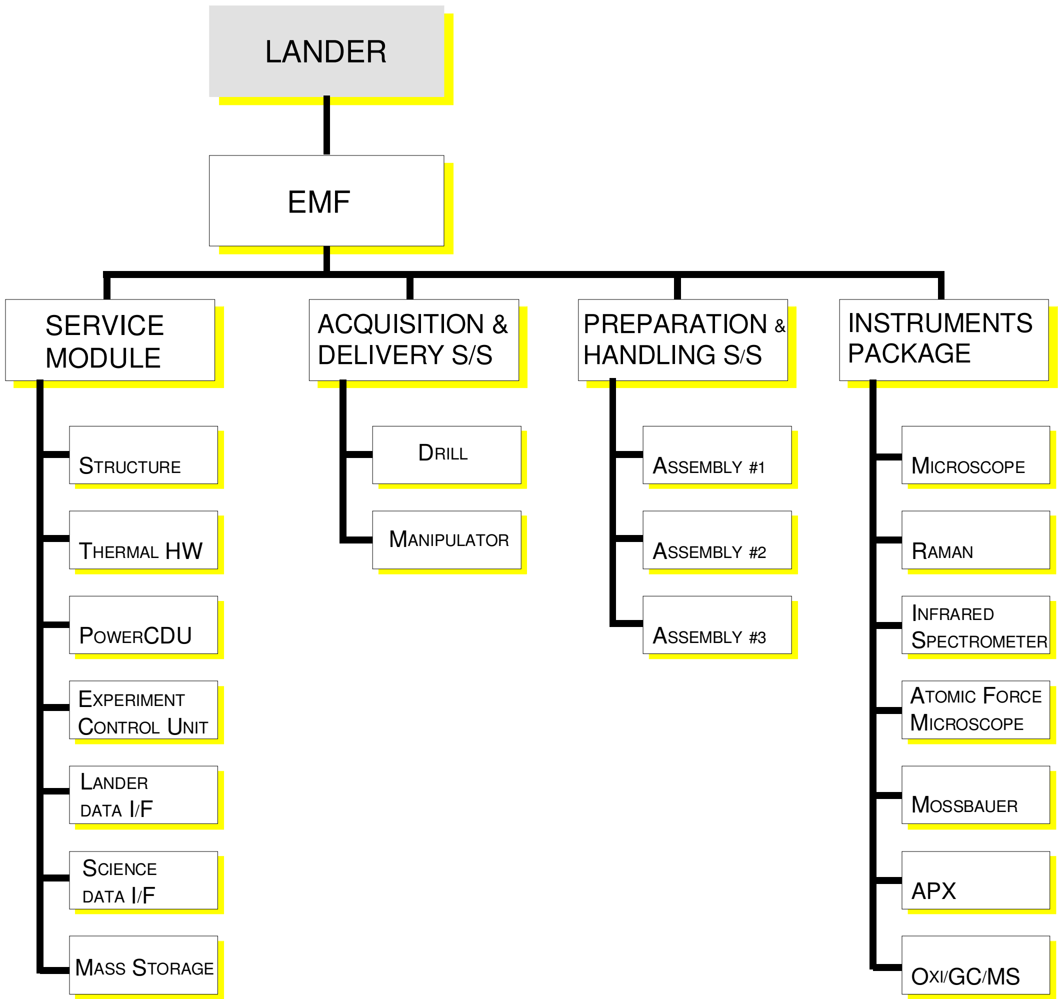


Fig.4.1-2 EMF HW Tree

EMF will provide the infrastructure for the scientific instruments:

- mechanical structure to accommodate the scientific instruments;
- payload control sub-system (interface between the scientific instruments and the lander spacecraft);
- power supply sub-system;
- thermal control sub-system for the entire payload including the environmental control of specific instrument compartments;
- acquisition of samples from sub-surface (drill);
- preparation of sample and distribution system.

4.1.1. Instrument Package

The EMF scientific measurements will be performed by a dedicated set of analytic tools; this "Instrument Package" is composed by:

- Microscope
- Raman Spectroscopy
- Infrared Spectrometer (2^{nd} priority)
- Atomic Force Microscope (AFM) (2^{nd} priority)
- Mossbauer
- APX
- Oxi/GCMS
    - Pyrolysis
    - Gas Chromatography
    - Mass Spectroscopy
    - Oxidant detection
    - Chemical Derivatisation

EMF shall provide the boundary conditions for best performance of these instruments. A fundamental step in the experiment chain is the preparation of the sample, after its acquisition from Mars subsurface, in order to make it adequate for subsequent analysis.

4.2. Block Scheme of EMF

On the basis of the operational requirements and the inputs from applicable documents, the block scheme depicted in Fig.4.2-1 has been defined.

The optional interface with the Rover has been considered along the early stage of present study, although this features is not foreseen in the Mars 2003/2005 missions.

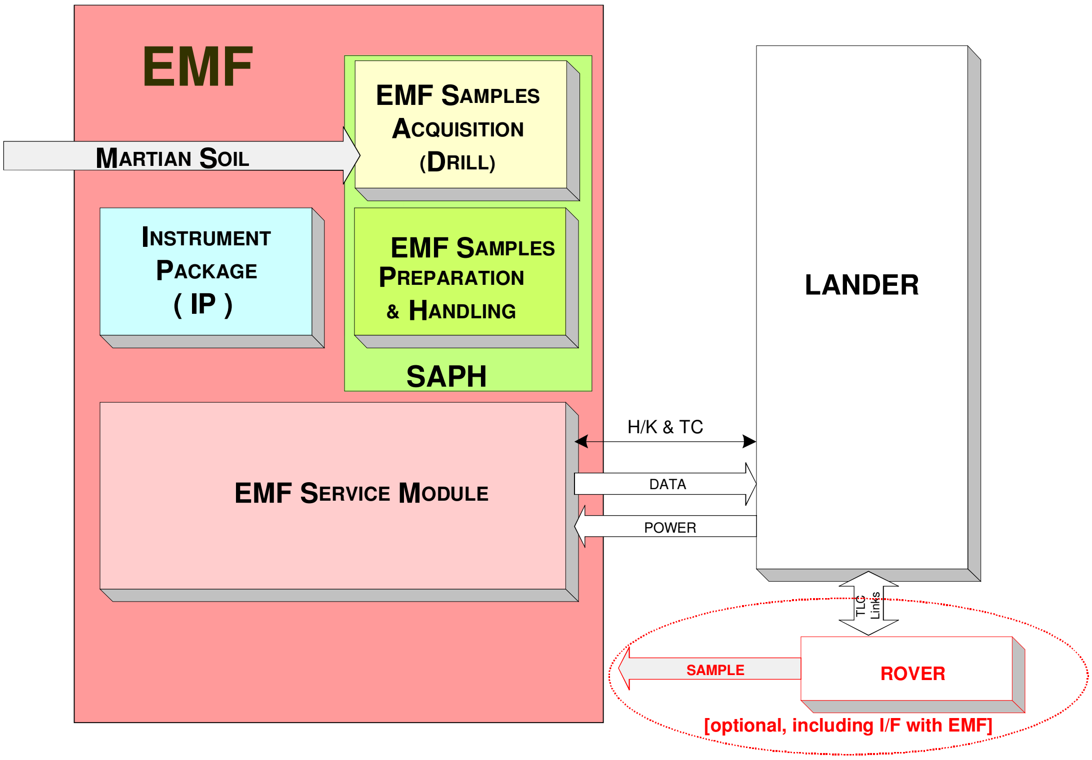


Fig.4.2-1 Overall EMF Block Scheme

Although functionally well separated, the Sample Preparation & Handling S/S will be closely integrated with the instruments that will receive the prepared sample, ready for observation or analysis.

4.3. Sample Preparation and Flow in EMF

On the basis of Science Team indications, devoted to maximise the scientific return of the analyses, the treatment process of the acquired samples have been defined. Instruments have been grouped according to the required treatment of the samples.

4.3.1. Sample preparation

Different methods for sample preparation and handling processes, after acquisition, have been evaluated during the study in conjunction with the definition of instrument characteristics and the scientific requirements.

We report in Tab.4.3.1-1 a summary of the required processes of samples for each instrument observation. All the processing of samples, as well as their overall handling, is demanded to the SPHS.

Optical Instruments require scan and focusing of the sample; presently these features have been implemented in the SPHS, in order to integrate in it the largest part of mechanical items, reducing at the maximum extent the complexity of the Instrument Package.

We report in Tab.4.3.1-2 the main requirements of optical instruments in terms of scan and focusing.

Experiment	**Sample Preparation method**
Microscope low magnification	Direct observation of the raw sample (core or loose soil); dust shall be removed from surface of core.
Microscope high magnification	Selected areas (order of sqmm) of the sample (core, or grains in loose soil) shall be observed. Dust shall be removed. Surface roughness shall be limited to depth of focus (order of µm's). Observation of fresh surface (broken core) could have high scientific interest.
Raman Spectrometer	
Infrared Spectrometer	
Atomic Force Microscope	Sub-µm investigation of natural surface morphology requires a raw sample.
Mossbauer	The sample, both core and loose soil, shall be powdered; then put in a container under instrument observation.
APX	
Gas Chromatography	The sample shall be powdered (amount: fraction of gram), then put in a small oven for subsequent selective heating up to 800°C.
Mass Spectroscopy	
Pyrolysis	
Oxidant detection	

Tab.4.3.1-1 Summary of Sample Processing

Instrument Interface	**AFM**	**Microscope hi-magnification**	**RAMAN**	**IR Spectrometer**
Preparation (prior operation)	X positioning (50µm/step) Y positioning (50µm/step)	X positioning (1.5 mm/step) Y positioning (1.5 mm/step)	X positioning (10µm/step) Y positioning (10µm/step)	Y positioning (38µm/step)
Support (at operation)	not needed	Z focusing (5 µm/step)	Z focusing (5 µm/step)	X scan (38 µm/step) Z focusing: (100 µm/step)

Tab.4.3.1-2 Sample Positioning for Optical Instruments and AFM

4.3.2. Sample Flow Operations

The basic operations of the EMF are the acquisition of a sample from Martian soil, from a pre-defined position and depth, the preparation of this sample for the subsequent analyses and the delivery of the sample to the various instruments. The breakdown of these operations and the relevant flow is reported in Fig.4.3.2-1.

This configuration fulfils all the functional requirements, including modularity. The Sample Preparation & Handling S/S has been split into three independent assemblies, each preparing and presenting the sample for a dedicated set of instruments requiring a common preparation of the sample. The milling station is duplicated (assembly 1 and 2), thus enhancing the overall reliability, but a solution sharing a single station has been studied.

Care has been put on the treatment of samples after examination, in line with Planetary Protection and Pollution/Contamination issues.

We report the foreseen operational procedure:

- The Manipulator Arm places the drill box, which contains the core sample, on the Assembly #3 into a sample container. Here the core sample is cut/ground in order to obtain a flat surface; then the Polishing/Cleaning station prepare the surface of the sample; some step can be by-passed, or changed, depending on characteristics of the sample (e.g. no polishing for loose soil, or for AFM observation). Instruments in this line of observation are Microscope, Raman spectrometer, IR spectrometer, and AFM. The Atomic Force Microscope is used to investigate the sub-micron morphology of grains or fresh surface of material.
- Mossbauer and APX require a milled sample: the Manipulator Arm places the drill box on the milling station, where the sample (core or loose grains) is ground. With the powder, the appropriate sample container is filled, with a defined thickness of material. The wells have a cap, which allows preserving and storing the samples after the analysis.

- The milling station operates also prepares sample to fill ovens, which need ground samples and heating (Oxidant detector, Gas Chromatograph, Mass Spectrometer).

After the completion of preparation procedure, the sample is presented to the relevant instrument for scientific observation.

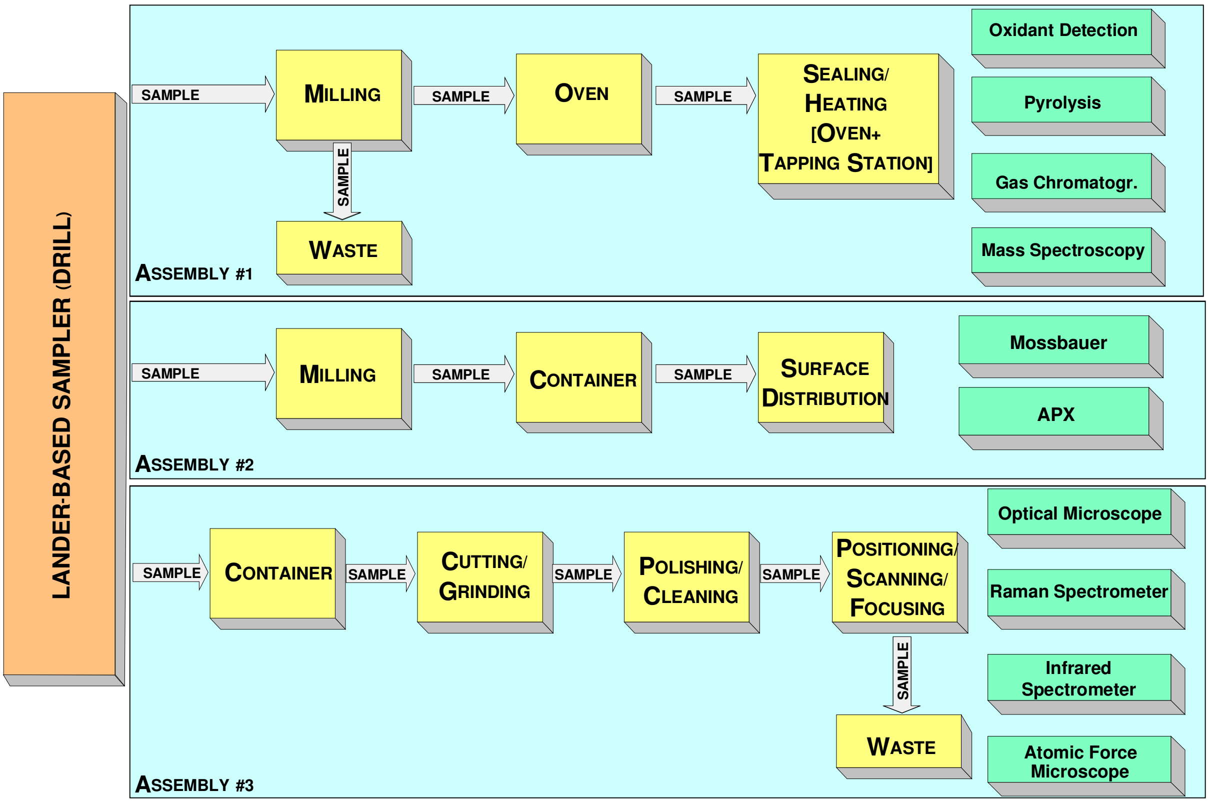


Fig.4.3.2-1 Flow Block Diagram of EMF

4.4. Functional Scheme of EMF

The proposed scheme, shown in Fig.4.4-1, is relevant to a fully stand-alone, autonomous facility.

The potential use of Lander resources (memory, computational power etc.) could reduce the number of electronics tasks, although this solution is not entirely compatible with the modular approach requirement.

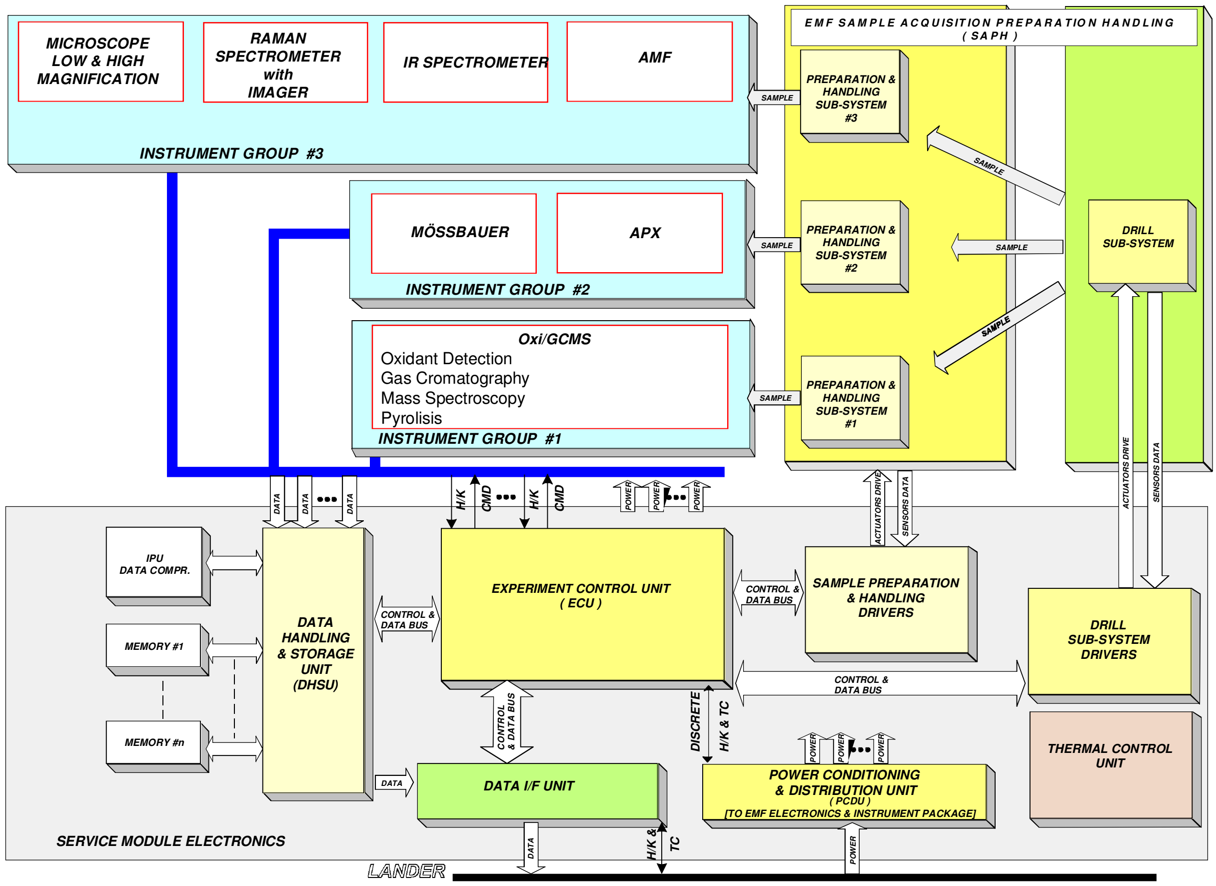


Fig.4.4-1 Functional Scheme of EMF

The Instrument Package is simply the collection of the various instruments. Each instrument is directly linked to the Service Module, in which the ECU has the responsibility to co-ordinate the operations.

The selected philosophy is to have each instrument quasi-autonomous (e.g.: each experiment will foresee a defined number of basic procedures, and their sequencing is commanded by ECU). Anyway, the definition of the sharing of tasks between ECU and the internal controller, if any, of each instrument will require a more detailed study and/or a deeper knowledge of the instrument, and possibly the harmonisation of interfaces. Our understanding of Mars 2003 mission requirements is that a very deep integration among the various units is fundamental the cope with overall available resources (mass, power); anyway we are duly considering the SOW requirement for a fully modular system.

An important point that has been considered in present architecture is the suitability of instrument to EMF interfaces. The SOW requires to exploit the use of existing or under development instruments for space / planetary missions; this solution could put constraints in the architecture of the overall EMF system, just for I/F or operational aspects. This point is not fully closed, due to the difficulty in obtaining detailed information about instruments from companies/institutes external to our team.

4.4.1. Service Module Architecture

The Service Module is constituted by the following major items:

- **Mechanical support structure** for the Instruments Package, SAPH System and other facility service elements, providing also the mechanical interface with the hosting Lander. The mechanical structure shall be conceived to allow the critical items of the facility to withstand the very complex solicitation sequence coming from the launch from Earth, landing on Mars.
- **Thermal conditioning of EMF**. Mars's temperature spans in a very wide range with lowest limit around -140°C. (The actual temperature range will depend on mission profile). Accordingly, a careful EMF thermal design shall be conceived taking into account from one side the need to protect temperature critical parts and from the other side the obvious constraint to minimise power consumption dedicated to active thermal control. To this purpose the preferred approach is to allocate the electronics in a unique box, leaving as external devices the instruments front-end and actuators. In addition the electronics unit and instruments shall be covered with suitably painted shields to reduce heat dispersion towards the Mars environment.
- **EMF Electronics.** The envisaged baseline foresees the allocation of all electronics functions in a single box.

Referring to NASA missions 2003 and 2005, it has been assumed as baseline that all communication activities are assumed to be in charge of the Lander which has a wired connection with EMF for data / command exchange.

The main functions of the electronics have been identified and the general approach followed in defining this preliminary architecture is to allocate to each unit sufficient operational autonomy and resources to allow independent execution of specific tasks. This means that the Control Unit shall generate high level commands to other units, define the overall operating mode of the facility, monitor the housekeeping data and take possible countermeasures in case of problems (e.g. failure of an instrument). This configuration should allow large autonomous operations to the facility. Any action will generate some telemetry data towards the Lander that in turn could communicate the actual EMF status to Earth.

4.4.2. Data communication resources

EMF science capability could be constrained by the allocation of data return resources. The 2003 mission foresees a maximum amount of data transmitted by all the AP, that here we can assume to include EMF, of the order of 10 Mbit per SOL, with a total figure of 100 Mbit up to SOL 65, and further 50 Mbit up to SOL 90 (ultimate end time for mission). This is a very stringent requirement; for instance a single 1024x1024 image (hypothetically provided by a microscope) could result in a 25 Mbit (un-compressed) size.

Anyway, the mission is not presently defined; for this reason we'll face the data rate budget with the figure of 10 Mbit per SOL (reference mission), but we'll consider also the possibility to benefit of a larger data communication capability.

4.4.3. Available electric power and computational resources

The available power is related to the lander operations (7 hours for day operations and 17 hours for night operations, NASA '03/'05 missions). Several EMF experiments could be carried out during night-time, provided that the limited power budget and the lander computational and communication resources are suitable.

To cope with available power resources the various equipment in EMF shall be operated in sequence, benefiting of the relatively low constraints in time duration of the experiments.

4.5. Operations time-line

EMF operations could follow a pre-flight defined timeline (with capability to update it by uplink), consisting of a sequence of elementary actions for each equipment, of which is fully defined and known:

- input status of instrument
- needed resources (power, communication, etc.)
- execution time
- effects on sample under processing (if applicable)
- final status of instrument
- fault diagnosis and handling

The central unit will activate the subsequent procedure after reception of the status telemetry, otherwise will start a recovery routine.

4.6. Configuration Drawings of EMF

In this paragraph the EMF synthetic configuration drawings are reported.

EMF has been conceived as composed by two main physical units: the first is the assembly of the Sample Acquisition, Preparation and Handling (SAPH) System and of the Front-Ends of the Instruments Package, the other is the electronics box that houses all the electronics boards of SAPH and Instruments. Inclusion of electronics in a dedicated box has the advantages to facilitate the mechanical allocation, easier thermal control (due to Martian very stringent environment), easier de-contamination and cleaning procedures (electronics should undergo to different de-contamination procedures with respect to the SAPH and Instruments front-ends). The two physical units are connected through a set of cables.

This study of EMF has started with this approach. In Fig.4.6-1 we present the first tentative of mechanical implementation of EMF on a hypothetical Lander. The sample-preparation stations are on the lateral sides of the Deployment Device, in order to be directly fed by the drill with the sample core. In such a hypothesis, the electronics box (dotted line) is allocated underneath the Lander plate (balcony) for optimal thermal insulation.

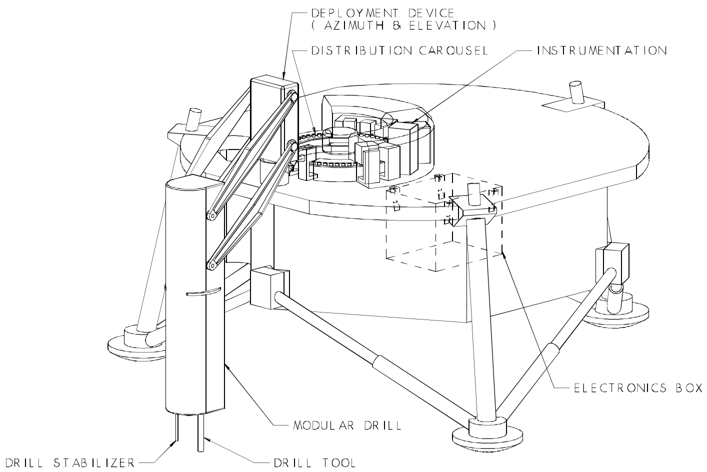


Fig.4.6-1 EMF on Lander, Drill Operation (pictorial view)

On the balcony, near to the edge, there is the Deployment Device, which has the task to move and manage the drill. In Fig.4.6-1 the Deployment Device has leant the drill on the Martian ground and the drill is penetrating the ground. On the opposite side of the Deployment Device the Distribution Carousel, with all the instruments around, is fixed beneath the Lander balcony.

This configuration evolved along the study, with the main outcomes that are outlined here below.

The drill require a powerful manipulator arm, in order to cope with the NASA '03/'05 Lander constraints (mainly the Lander deck height from soil surface, 1.7m).

The SPHS shall be integrated with the instrument in order to permit a thorough presentation of the samples to the instruments' observation (e.g., accurate focusing or scan of samples in front of optical instruments).

Along the study the sample preparation, for each experiment, was traded off versus the complexity of the system and the scientific return, and consequently the procedure was defined. The requirements for sample preparation led to three main different processes, depending on the set of observation instruments. For this reason we identified three separate assemblies, two of them could share a common milling device.

A compact configuration is shown in Fig.4.6-2, where the option with a single milling station is presented.

In this configuration the Instruments (Oxi/GCMS is not shown) are tightly integrated with SPHS. This configuration exhibits a single mechanical interface to the Lander, and seems suitable to minimise the amount of thermal insulation around it. Anyway, different options can be implemented, in order to cope with specific interface requirements with Lander, although the presented one seems adequate in terms of compactness and modularity.

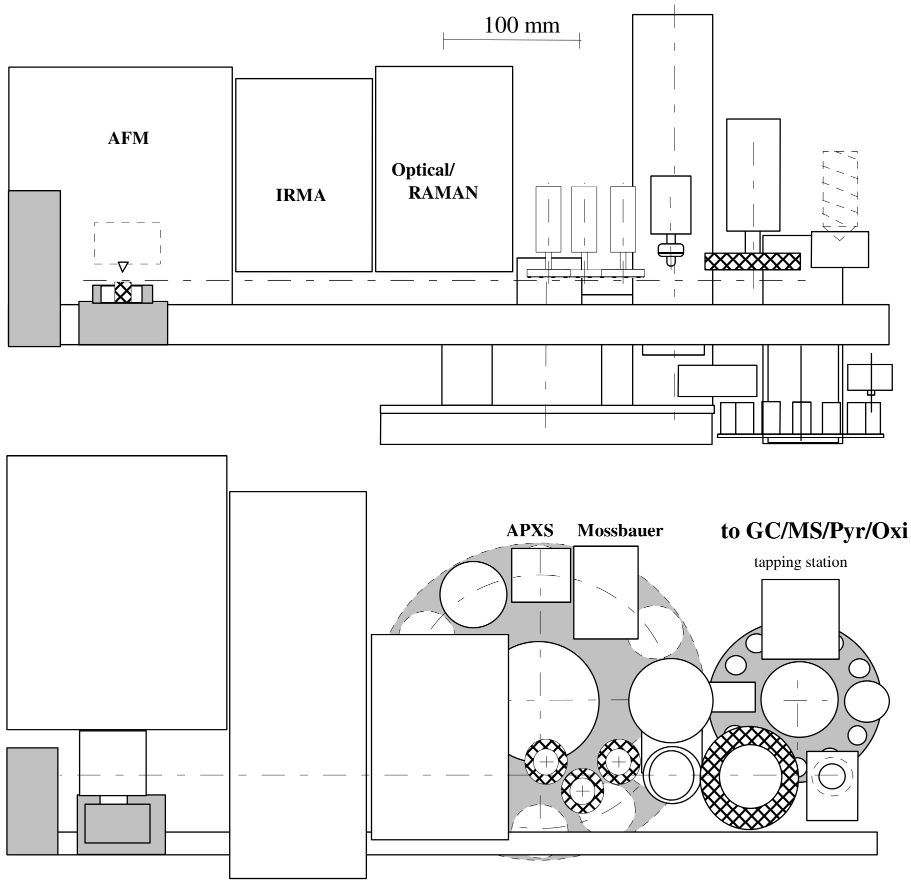


Fig.4.6-2 EMF, possible integration of instruments and SPHS
(only tapping station of Oxi/GCMS instrument is shown)

The Manipulator Arm, able to move the Drill Box, can be placed elsewhere on the Lander deck, with the only constraint to be able to discharge the sample into the input ports of SPHS.

Fig.4.6-3 shows:

- Drill Box, including:
    - drill tool,
    - extension rods (to reach 1.5 m depth)
    - sample transfer mechanism (loader);
- Manipulator Arm (positioner):
    - moves the drill box to different locations (stowage, surface, instrumentation and MAV loading), 4 degrees of freedom arm;

Present version is the one compliant to NASA '03/'05 Lander (manipulator arm) and EMF drilling requirements.

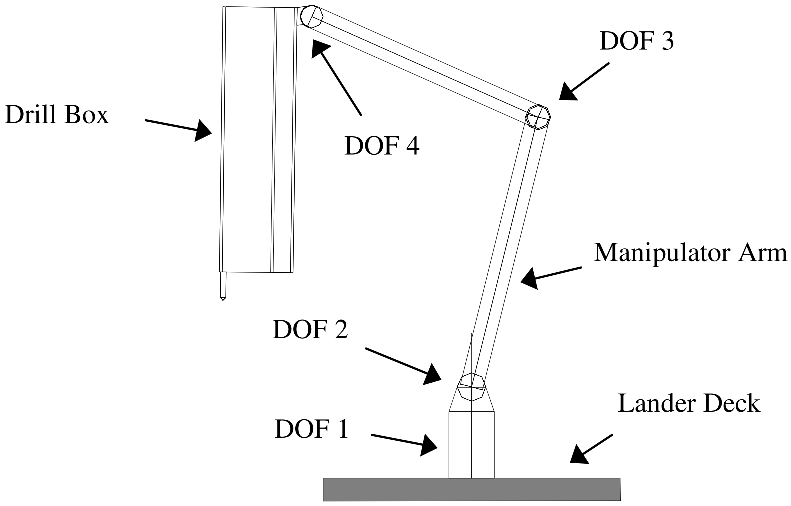


Fig.4.6-3 Drill Box and Manipulator Arm (4 DOF, 1.7 m deck height capability) on Lander

We remark that the characteristics of Manipulator Arm are strongly dependent on the Lander characteristics and the Drill Box accommodation on it.

5. DRILL SUBSYSTEM

The scope of Drill Subsystem is to acquire soil samples, whichever is their nature, and to deliver them to Sample Preparation and Handling for Sample processing. The main specifications of Drill (Sample Acquisition and Delivery Subsystem) are reported in Tab.5-1.

Requirement	Definition
Maximum Sampling Depth	at least 1.5 m
Martian Soil Properties	- reference materials: ‘Sand’ (unconsolidated): grains 2 - 6 x 10^{-2} mm ‘Tuff’: matrix 8-20 MPa, inclusions up to 100 Mpa ‘Basalt’: homogeneous, about 100 Mpa - materials distribution over the sampling depth: 30 % ‘Basalt’ + 60 % ‘Tuff’ + 10 % ‘Sand’
Accommodation	- on fixed platform above Martian surface (TBD Lander - NASA type as reference); - deliver samples to TBD position(s) on the Lander; - adjustable entry hole (along a TBD range)
Sample Characteristics	- solid core (when material allows), 7÷8 mm diameter; - loose sample (‘Sand’); - quantity of 1 - 2 cm^3

Tab.5-1 Summary of Main Requirements of Drill S/S

In order to cope with Mars 2003/2005 Lander characteristics a manipulator arm is required; the Drill box and the Manipulator arm are sketched in Fig.5-2. The Main elements are:

- Drill Box, including:
    - drill tool
    - carousel with sample containers
    - sample transfer mechanism (loader).
- Manipulator Arm (positioner): moves the drill box to different locations (stowage, surface, instrumentation and MAV loading), 4 degrees of freedom arm.

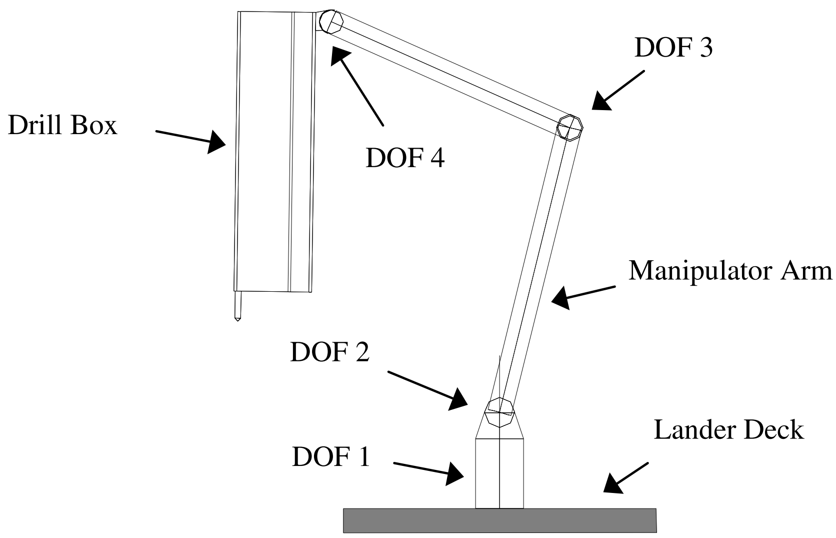
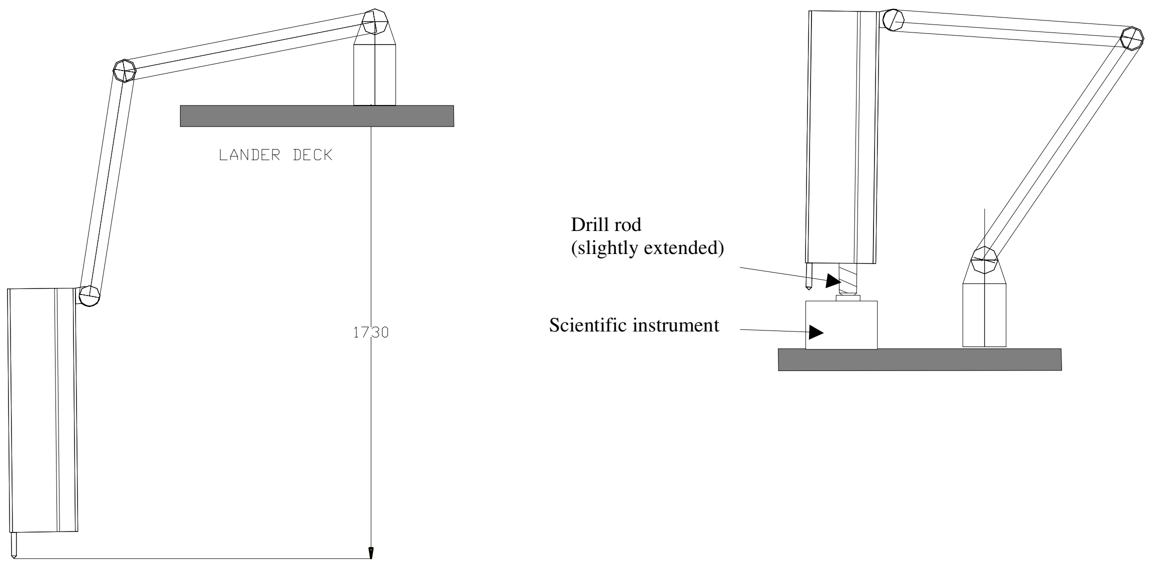


Fig.5-1 Drill Box and Manipulator Arm (DeeDri in '03/'05 project)



Sampling Position

Sample Discharge Position to Sample Preparation & Handling S/S

Fig.5-2 Drill Box and Manipulator Arm Operations (drilling and sample discharge)

The four DOF Manipulator Arm can be simplified in case of smaller Lander, closer to soil surface, as depicted in Fig.5-3

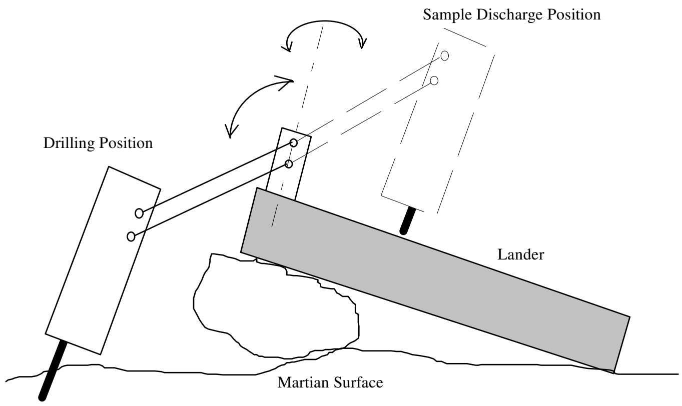


Fig.5-3 Simplified Manipulator Arm

The schematic of acquisition procedure is reported in Fig.5-4. It is worth noting that the selected technical solution of the Drill system is capable to acquire both hard rock cores as well loose soil (sand-like).

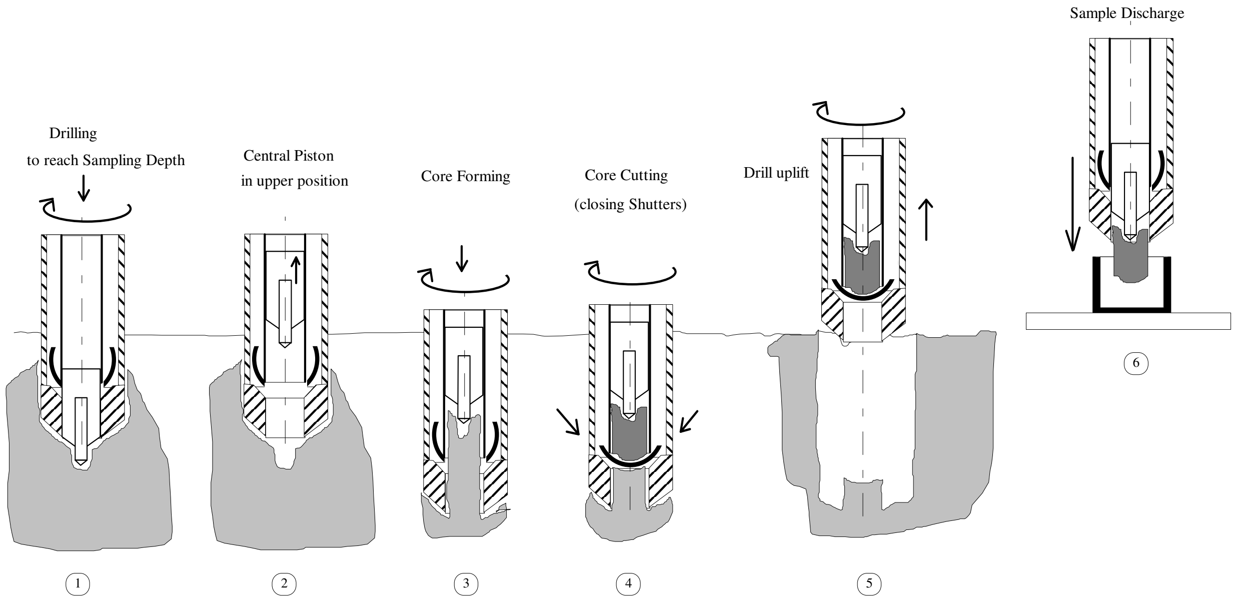


Fig.5-4 Sample Acquisition Procedure

The required maximum acquisition depth, i.e. 1.5 meter, is a challenging issue. Due to encumbrance constraints arising from accommodation on Lander, the Drill box size is compatible with a rod length of the order of 0.5 m, thus requiring the implementation of an extensible rod.

The concept is explained in Fig.5-5.

Main elements of extensible rod Drill Box are:

- • Drill Tool:
  performs drilling by cutting,
  incorporates sample acquisition mechanism;

- Drill Carriage:
  rotates the Drill Tool,
  applies translation thrust;

- Extension Rods (with soil transport auger);

- Extension Mechanism: performs assembling/disassembling actions with Extension Rods

A preliminary design of the Extension mechanism has been carried out, demonstrating its feasibility.

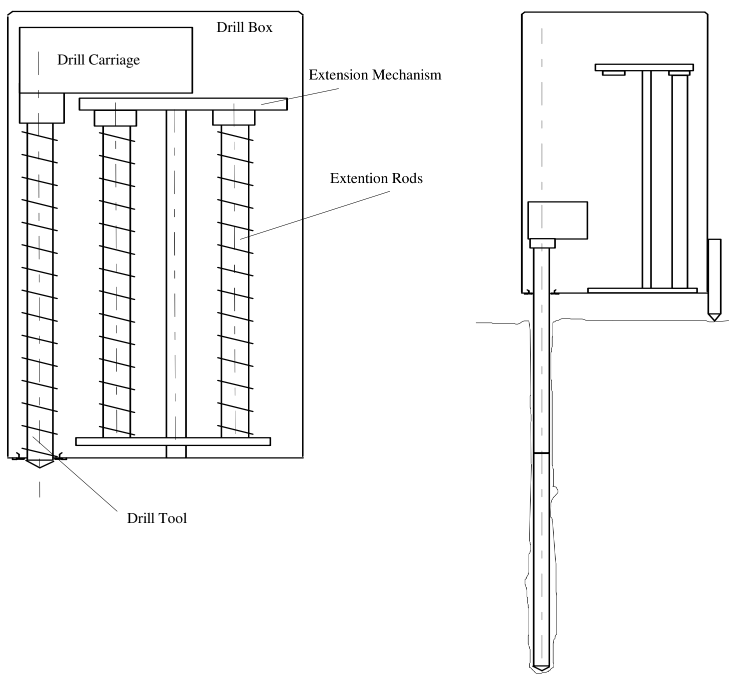


Fig.5-5 Extensible rod Drill Box

The mass breakdown with a budgetary evaluation of mass is reported in Tab.5-2. The main remarks are relevant to the mass of the Manipulator: 10 kg is the figure coming from the assumption to have the mechanical constraints of NASA 2003/2005 missions (i.e. 1.7 m Lander deck height); substantially lower figures are expected for a simplified manipulator.

The Drill system has been dimensioned to acquire 7÷8 mm diameter samples.

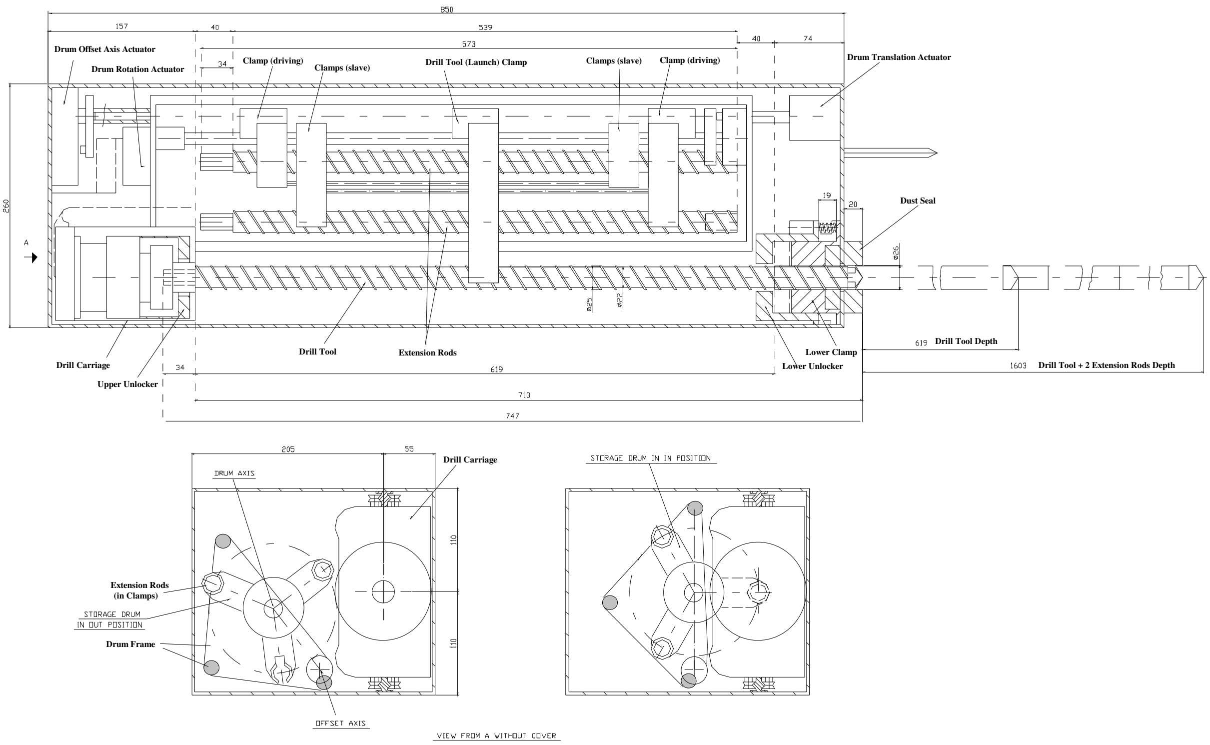


Fig.5-6 Extensible rod Drill Box

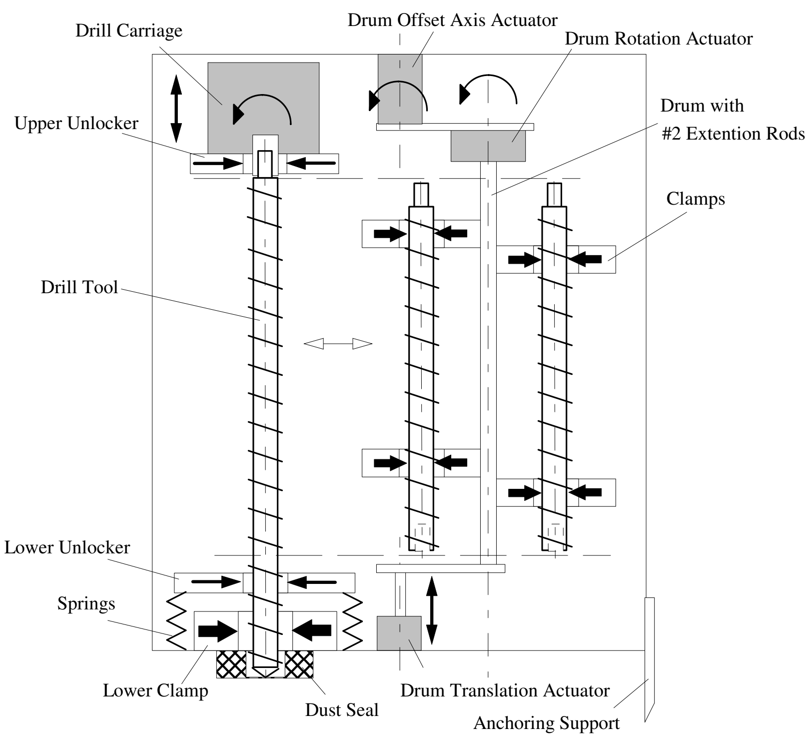


Fig.5-7 Extensible rod Drill Box

	mass (kg)	***remarks***
Drill Box *(including:)*	***9.8***	design within DeeDri envelope
Drill Tool	1.0	
Drill Carriage	2.3	including structure
Extension Rods	1.8	2 extension rods
Structure	2.1	with embedded guides and rack
Extension Rods Drum	2.0	with mechanisms
Harness	0.6	including connectors and moving cables
Manipulator Arm	***10.0***	4 degrees of freedom arm for NASA 2003/05 type Lander
TOTAL	***19.8****	
Configuration and size of the Manipulator Arm strongly depend on Lander geometry and deck height with respect to a soil surface; In case of a dedicated exobiology mission proper Drill-oriented Lander design should allow significant mass saving.		

Tab.5-2 Drill Mass Budget

6. SAMPLE PREPARATION & HANDLING S/S

Scope of Sample Preparation and Handling Subsystem within EMF facilities is to prepare samples acquired by Sampling Subsystem and support instrument operations.

The main requirements for SPHS are listed in Tab.6-1.

Requirements	Definition
Instrument Package Interface	first priority instruments: - Chemical Analysis (Oxi/GCMS) instruments, - APXS, - Mossbauer, - Optical Microscope (OPMI)/RAMAN; second priority instruments: - Infrared Spectrometer (IRMA), - AFM; minimum number of instrument work sessions (samples): 10
Accommodation	- shall be compatible with Additional Payload envelopes on NASA 2005 type Lander
Sample Material	shall demonstrate functional performances with the Reference Materials (TBC): ‘Sand’: unconsolidated, grains 2 - 6 x 10^{-2} mm ‘Tuff’: matrix 8-20 Mpa (inclusions up to 100 MPa) ‘Basalt’: up to 200 MPa, homogeneous
Sample Deterioration	- shall minimise samples mixture (from different depth); - shall provide protection from UV/Dust environment

Tab.6-1 Main Requirements for SPHS

According to system requirements, SPHS has been split into three assemblies (handling lines) to allow accommodation in different locations on the Lander deck (as Additional Payloads).

Assemblies serve groups of instruments with similar sample handling requirements:

- Assembly 1 serves Chemical Analysis instruments (Oxi/GCMS) that require:
  - mechanical oven/tapping station interface;
  - small amount of sample;
  - fast sample processing.
- Assembly 2 serves APX and Mossbauer spectrometers that require:
  - covering large field of view with sample material;
  - long processing time (hours);

- Assembly 3 serves Optical Microscope, RAMAN spectrometer, AFM and IR instruments that require:
  - working on ‘surface’ (small field of view is sufficient for one acquisition);
  - not critical on processing time;
  - sample surface preparation (flattening, polishing, cleaning);
  - scanning functionality.

The three Assemblies have been sketched in Fig.6-1. Each Assembly is independent from the others and can be placed in any position on the deck with the only constraint of accessibility from the Drill/Manipulator Arm for sample discharge.

Should be priority given to compactness and mass saving, an integrated SPHS design is available, shown in Fig.6-2.

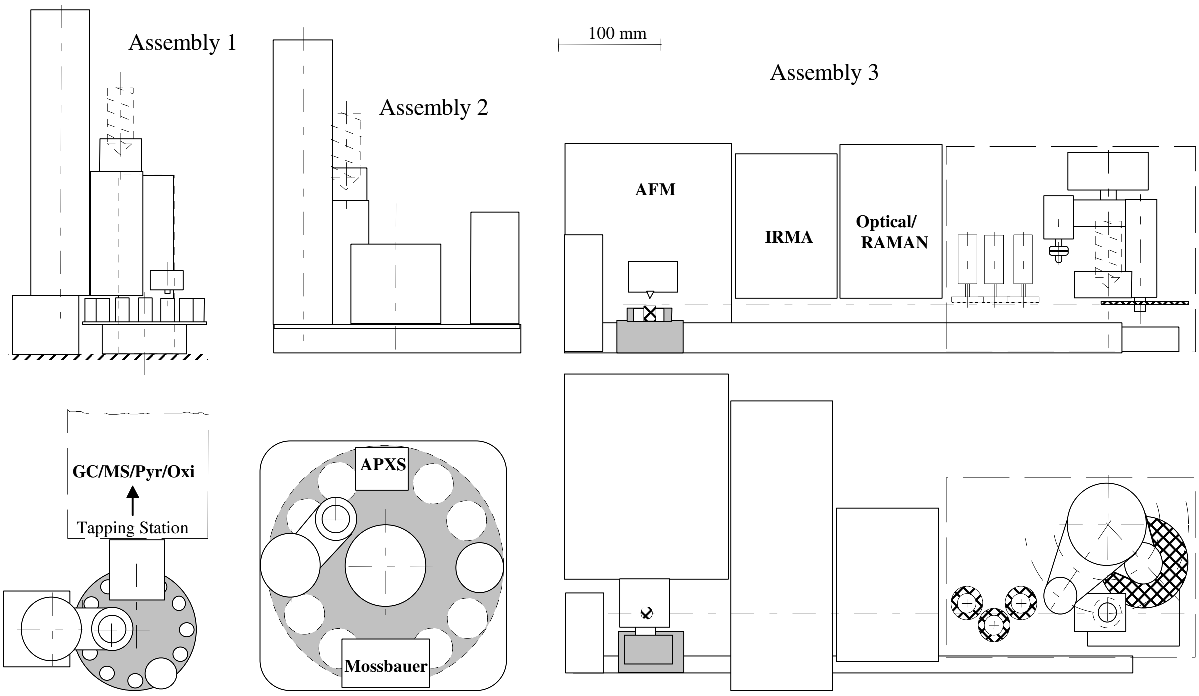


Fig.6-1 SPHS (Three Independent Assemblies)

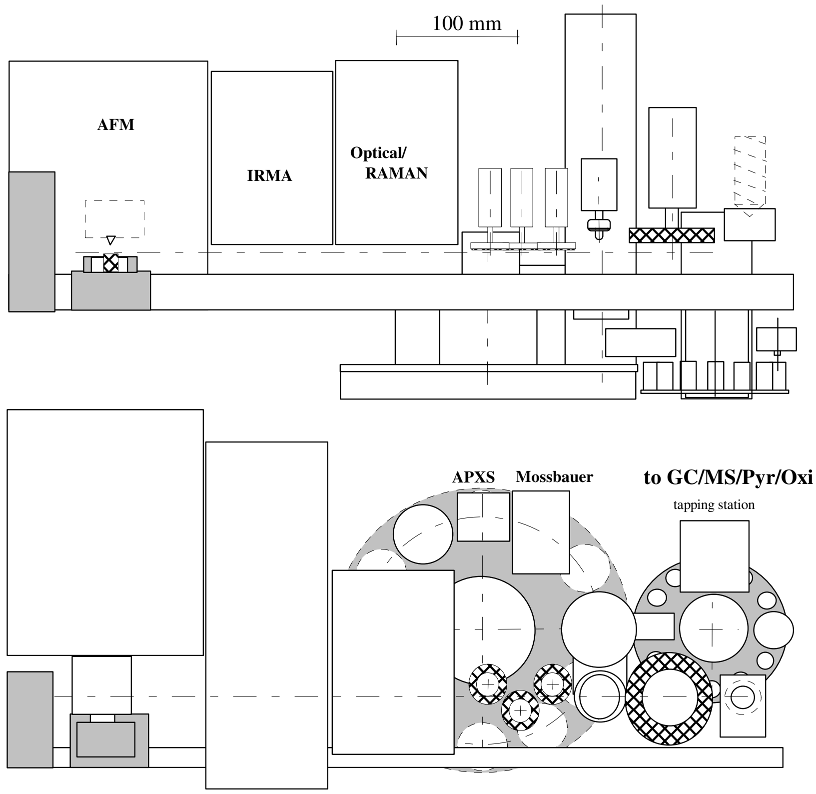


Fig.6-2 SPHS (Integrated Assemblies)

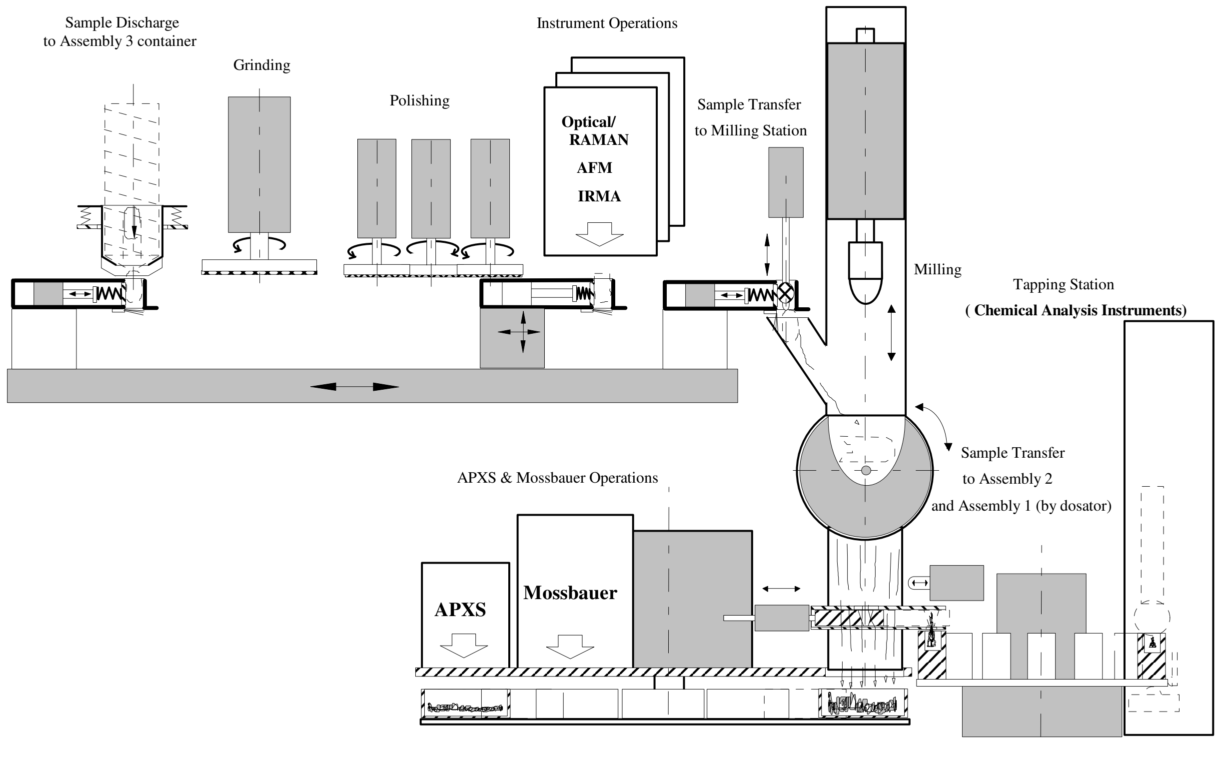


Fig.6-3 SPHS (Integrated Assemblies) Sample Processing Flow

The estimation of mass for the two SPHS implementation hypothesis is reported in Tab.6-2 and Tab.6-3, respectively.

	mass (kg)
Assembly 1	***1.5***
Assembly 2	***2.0***
Assembly 3	***2.5***
TOTAL	***6.0***

Tab.6-2 SPHS (Three Independent Assemblies) Mass Budget

	mass (kg)
Combined Assembly 1+2+3	***5.0***

Tab.6-3 SPHS (Integrated Assemblies) Mass Budget

7. INSTRUMENTS

In this chapter we report the achievement regarding the Instrument that will be included in EMF.

7.1. Optical Instruments

A survey of instruments suitable for planetary exploration missions has been carried out; as outcome of this survey the possible candidates have been outlined.

During the study we identified a possible instrument that received the interest of Scientific Community; it is a Raman Spectrometer integrated with an Optical Microscope able to provide an image of the area surrounding the spot under Raman excitation.

The characteristics of the Optical experiments are summarised in Tab. 7.1-1 to Tab. 7.1-4.

Instrument	**OPMI** **(Optical Microscope)**	**RASP** **(Raman Spectrometer)**	**IRMA** **(I/R Spectrometer)**
Spatial Resolution	1.5µm / pixel	≈10 µm spot	38 µm / pixel
Waveband	Visible range	≈600÷700 nm excitation	1 ÷ 5 µm
Spectral Resolution	-	10 cm^{-1} (≈0.5 nm for 680 nm excitation)	10 nm
Sample preparation & presentation	▪ solid-polished ▪ solid-raw/broken ▪ solid-grains	▪ solid-polished ▪ solid-raw/broken ▪ solid-grains	▪ solid-polished ▪ solid-raw/broken ▪ solid-grains
Amount of sample material	1.5x1.5 mm² minimum	▪ few µm minimum ▪ several points for a better statistics	10x10 mm² or lower

Tab.7.1-1 Performed Analysis

Instrument	**OPMI**	**RASP**	**IRMA**
Operational requirements *(rough estimates)*	10 min. for each image	10 min. for each spectrum	▪ non-heated sample ▪ one hour for square image 270x270pixel x430 spectral lines
Thermal	Thermal Conditioning	Thermal Conditioning	Cool optics (TBD) and cryo-cooled detector
Environmental	Protection from dust	Protection from dust	Protection from dust

Tab.7.1-2 Main Operative Requirements

Instrument	OPMI	RASP	IRMA
Single acquisition	1.5x1.5 mm² image	single "grain" (≈10µm)	38µm x 10 mm
Focusing need (Z-scan)	≈ 5÷10 µm / step	≈ 5÷10 µm / step	≈100÷200 µm/step
X- scan	≈1.5 mm/step	▪ non-imaging, grid: ≈1.5 mm/step ▪ imaging: ≈10µm/step	38µm/step
Y- scan	≈1.5 mm/step, requires a dedicated mechanism	▪ non-imaging, grid: ≈1.5 mm/step ▪ imaging: ≈10µm/step	not required
Single acquisition	1.5x1.5 mm² image	single "grain"	38µm x 10 mm

Tab.7.1-3 Scan / Focusing Requirements

<table>
<tr><th>Instrument</th><th>OPMI</th><th>RASP</th><th>IRMA</th></tr>
<tr><td>Raw data amount for one uncompressed measurement/scan/ spectrum</td><td>1.5x1.5 mm² image:
34 Mbit</td><td>single "grain" spectrum:
10 kbit</td><td>10x10 mm² image*spectrum cube:
380 Mbit</td></tr>
<tr><td>"Flight" Calibration</td><td>Reference targets</td><td>Reference targets</td><td>Reference targets</td></tr>
<tr><td>Combination with other instruments</td><td colspan="2">Micro-Raman: integrated instruments</td><td>complementary to Raman</td></tr>
<tr><td rowspan="2">Power requirements</td><td>6.6 W max</td><td>10.8 W</td><td>10 W max</td></tr>
<tr><td colspan="2">≈12 W max</td><td></td></tr>
<tr><td rowspan="2">Mass</td><td>250 gr (Beagle 2)</td><td>1.5 kg (Athena)</td><td>1400 gr</td></tr>
<tr><td colspan="2">≈1350 grams</td><td></td></tr>
<tr><td rowspan="2">Size</td><td>150 cm³</td><td>250 cm³</td><td rowspan="2">125x265x100 mm</td></tr>
<tr><td colspan="2">150x150x100 mm</td></tr>
</table>

Tab.7.1-4 Main Interface Data

7.1.1. Optical Microscope

A microscope for planetary environment use is under development for the Beagle 2 Lander; its characteristics, that mainly fit the EMF requirements, are summarised here after.

The Beagle 2 Microscope present design is based on a micro-camera, with 1024x1024 pixels CCD, equipped with a 10x lens of about 20 mm focal length and 7.5 mm aperture (0.167 of numerical aperture). In this case, the microscope will have a field of view on the sample of 1.5x1.5 mm. The optical resolution is 3 μm, leading to a pixel scale of 1.5 μm/pixel.

The microscope is equipped with an illuminator, based on a concentric set of low power, super-bright LED's working at the four wavelengths of 450, 535, 610 and 850 nm enabling colour imaging (30 nm bandwidth). The working distance is about 20 mm, while the depth of focus is about 10 μm. The Beagle 2 mass/volume requirements seems quite favourable, with a mass around 200 grams and a volume of 0.15 dm^3.

The micro-camera (shown in Fig.7.1.1-1), which the microscope is based on, is composed of three parts, the optics, the opto-mechanical interface, and the electronics. The electronics is packaged in a 3D-stack multi-chip module, and the sensor used is a 1024x1024-pixel CCD chip.

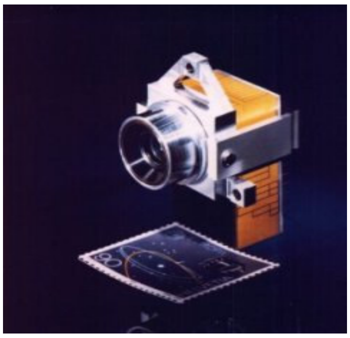


Fig.7.1.1-1 Microcamera (prototype)

High integration is obtained by including the sensor in the 3D packaging, and the mechanical support for the optics was designed in order to minimise mass, taking into account vibration stress during launch and thermal constraints during the missions [+50 to –150 ºC]. Lightness (35 g including optics, opto-mechanical interface and electronics) and compactness of the micro-imager, as well as its low-temperature behaviour, makes it a very cost-effective solution for resource-critical mission.

The sample focusing and scan will be implemented by the SPHS, with a mechanism common to all the Optical Instruments. The Beagle 2 microscope could be upgraded by implementing two levels of magnification, as desired for an image of the whole sample in order to subsequently select the most interesting areas for high magnification observations.

An important point is the sample preparation. Two different philosophies are under evaluation. The first one assess that the he sample needs to be cut and polished with a residual roughness less than 10 μm, on a useful area of at least 1.5 x 1.5 mm, to fully exploit the microscope capabilities. On the other hand, the possibility to observe unpolished rock surfaces adds some information especially for the detection of microstructures of biological origin. The first method simplifies the focusing and scanning system, while the second one simplifies the sample preparation station.

7.1.2. Raman Spectrometer

Raman spectroscopy is a useful technique to study the chemical and mineralogical composition of a planetary surface, since it allows us to probe chemical bonds and in some cases the crystal lattice. The Raman Spectrometer operates by shining a small, laser beam onto a rock or soil sample and analysing what comes back. Almost all of the light that reflects or scatters off of the sample and back into the instrument's sensor head has the same wavelength as the original laser beam. A small amount of the light is shifted to a slightly different wavelength. This phenomenon is known as Raman scattering and it serves as a very reliable fingerprint for compounds and minerals. Among the various existing or under development instruments, which have been studied, the Athena Rover Raman Spectrometer is the one that best fits the EMF engineering and scientific requirements.

The instrument is composed by two parts: a probe head - including the sampling objective, the illumination laser, the relay optics and the filters - and the energy analyser, including the spectrometer, the detector, the data processor and the power supply. The two boxes are connected through electrical cables and optical fibers. Such design permits to package the probe in a cylinder of about 9x5x5 cm and the remote allocation of the other subsystem. This allows a good flexibility in the architecture of the instrument.

The above described design is able to detect Raman shifts from 100 to 4000 cm^{-1}, with a spectral resolution of about 4 cm^{-1}, well in line with the requirements of the Exobiology Multi-User Facility. The sample does not require preparation allowing the simplification of the samples preparation station.

The beam spot size is expected to be around 10 µm, thus allowing for determination of the composition of individual mineral grains.

Sketches of the Athena Raman Spectrometer (Probe Head and instrument Box) are shown in Fig.7.1.2-1.

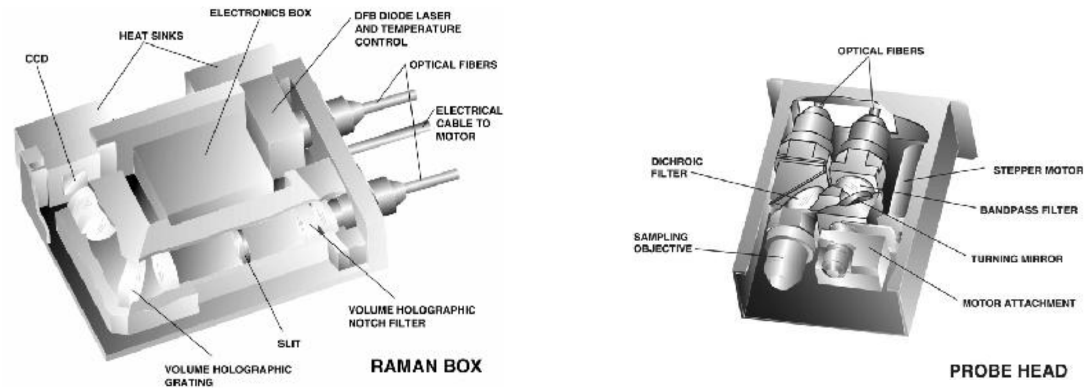


Fig.7.1.2-1 Athena Raman Spectrometer

Presently we can assume as baseline a configuration similar to the one in development for the Athena programme. Anyway, our application does not require, in principle, a fiber optic link between the probe head and the optical box. For this reason we could think to an integrated solution thus avoiding the power losses and temperature problems due to the fiber optics connections. It is anyway possible to use the versatility given by the optical/electrical link between the Raman Box and the Optical Head for an easier allocation of the instrument within the EMF architecture.

The proposed baseline requires the following resources:

- mass 1.5 kg
- power (peak) 2.5 watt
- overall volume 250 cm^3 (head size: 9x5x5 cm).

It is worth noting that the sample subjected to Raman analysis has to be accurately focused, due to the very small size of the excitation spot (tens of µm) and the corresponding depth of focus. This problem can be overcome if the Raman Spectrometer shares the microscope objective (used to focus the excitation beam on the sample) with the optical microscope. The microscope can then be used to focus the sample, using the same procedure already foreseen for the optical investigation, prior to carrying out the Raman analysis.

7.1.3. Infrared Spectrometer

IR spectroscopy is a useful technique to carry out analysis of minerals and organic, providing information complementary to Raman spectroscopy.

A novel instrument is presently under development by the Institute of Space Astrophysics of CNR-Rome-Italy; it is named IRMA (Infrared Microscope Analysis) and will fly on the NASA Mars Lander 2003/2005 missions. It is a microscope/spectrometer measuring the sample scattering characteristics in the 1÷5 µm spectral region (0.8÷5µm as goal). Main characteristics are reported in Tab.7.1.3-1.

Spatial Resolution	38 µm / pixel
Spectral Resolution	10 nm
Absolute Accuracy of Spectral Data	20 %
Relative Accuracy of Spectral Data	1 to 5 % (TBC)
Main range of sample reflectivity	10 to 40 %
SNR at 10% sample reflectivity	100 min
Depth of focus	To cope with sample roughness and planarity (external focusing mechanism could be necessary)
Area to be acquired	up to 10x10 mm
Size, Mass, Power consumption	3.3 dm^3 volume, 1.4 kg, 10 W max (all TBC)
Data rate	Compatible with Lander capability: 10 Mbit/day
Required support from System	Housing, thermal control, power distribution, data handling

Tab.7.1.3-1 Main characteristics of IRMA

This Instrument benefits of heritage from past instruments, mainly from the development of VIRTIS-M (Rosetta mission), that is a spectrometer sharing several aspects (both conceptual and technological) with IRMA. It is expected that the use of already developed hardware will minimise risks and development costs. A schematic concept of the instrument is shown in Fig.7.1.3-1.

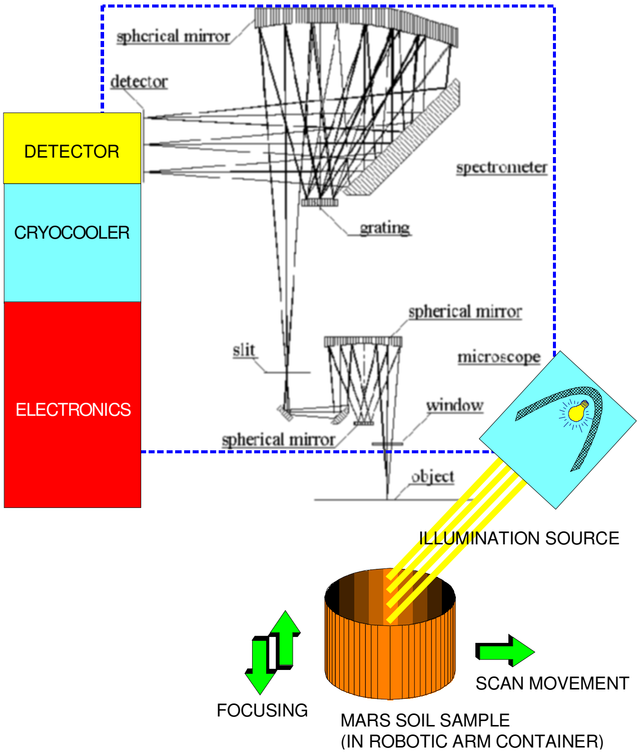


Fig.7.1.3-1 Schematic concept of IRMA instrument (Optics design by Dr A. Romoli)

IRMA will re-use a space-qualified detector 475x270, 38µm element size, with high sensitivity in the 1÷5µm waveband, developed in VIRTIS-M project. This detector will permit to obtain a spectral resolution of (5µm-1µm)/475 = 8.4 nm. Suitable optical filters on the window of detector package will filter out the second order spectrum. The scheme of image cube acquisition is shown in Fig.7.1.3-2.

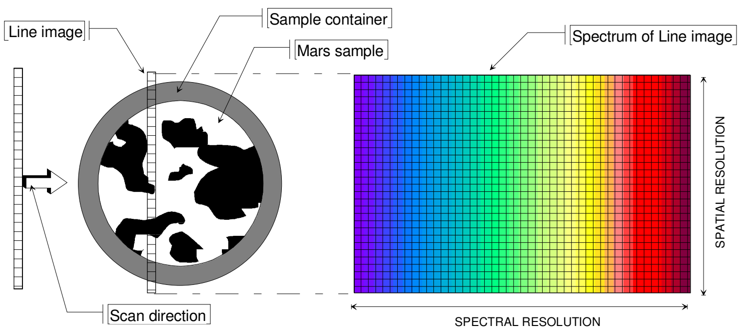


Fig.7.1.3-2 Scheme of image cube acquisition

From the spatial resolution standpoint, the magnification of the microscope is 1x (*i.e.* 38µm / pixel resolution). This solution meets the scientific requirement to retrieve reflection spectra from homogeneous grains (size <100µm) of Mars's terrain, and is compatible with non-critical optical design. Moreover it makes possible to image the whole sample with a single scan (the length of the line image is 270x38µm = 10.26 mm). The 1x microscope is implemented with a highly performing Offner configuration. Furthermore it has entrance and exit pupils perfectly telecentric.

In order to measure the spectral reflectivity of the sample under observation over a wide waveband range, the sample will be illuminated by an incandescent lamp using as light concentrator an ellipsoidal mirror with the lamp filament placed in a focus.

The proposed baseline requires the following resources:

- mass 1400 g
- IR spectrometer power <10 watt
- overall volume: several mechanical configurations have been studied; one of these is shown in Fig.7.1.3-3, with envelope size 265x125x100 mm.

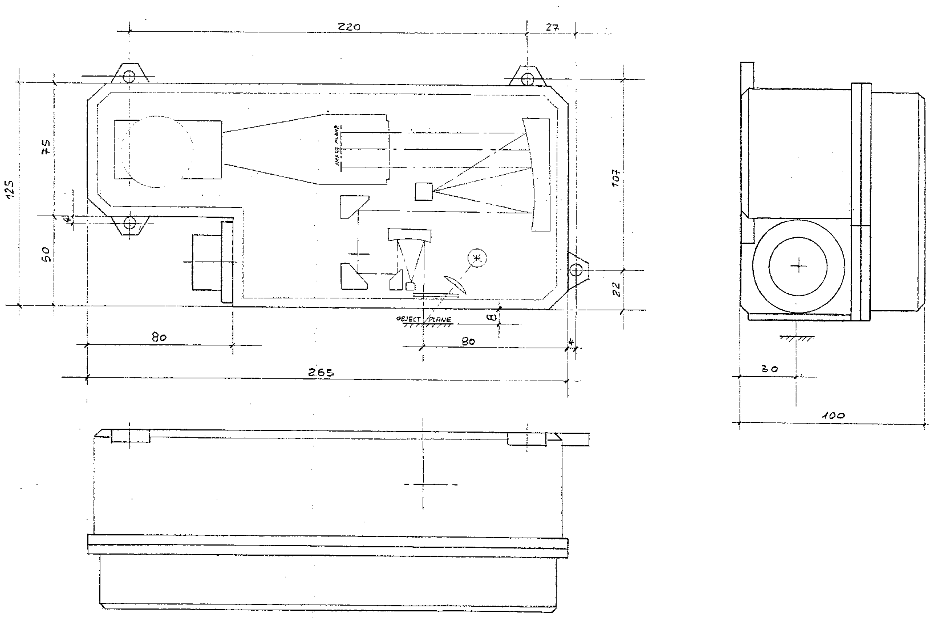


Fig.7.1.3-3 Tentative IRMA Layout

The power budget assessment is reported in Tab.7.1.3-2.

Item	Supply Voltage (V)	Power Consumption (mW)		
		Typ.	Max.	Peak
Electronics	+ 5	200	380	650
	+ 12	840	1020	1500
	- 12	540	610	820
Lamp	+ 21	3300	3400	3400
Cryocooler	+ 21	4000	8000	8000
TOTAL	Cooldown	8000	8000	8000
	Normal operation	8880	9410	10370

Tab.7.1.3-2 IRMA Preliminary Power Budget

7.1.4. Integrated Microscope-Raman (MIRA instrument)

The present section outlines the integrated instrument optical microscope plus Raman spectrometer. To better exploit the payload performances, the two instruments will be integrated so to use as much as possible common subsystems (*e.g.* the objective lens). The proposed instrument will allow collecting microscope images and/or a Raman spectrum of the centre of the field of view. Further spectra could be collected by translating the sample stage. This characteristic has the great scientific advantage that the sample is observed exactly in the same point by means of the optical microscope and the micro-Raman. This feature cannot be achieved easily using two separate instruments, and in any case with a lower positioning precision.

To the best of our knowledge, no existing instrument suited for space applications ensures this high degree of hardware integration and flexibility.

The following engineering benefits can be envisaged:

- Reduction of mass and size wrt separate instruments
- Single focusing procedure for both the instruments Microscope and Raman (through Microscope Objective: single scan and focusing mechanism for both the instruments)
- Single delivery operation of sample
- Thermal control of a single unit

On the other hand, it is possible to foresee the following drawbacks

- The system feasibility is under evaluation, therefore MIRA is in a early development stage wrt existing or already under development systems.
- The mechanical and optical architecture is slightly complex wrt each single instrument.

Fig.7.1.4-1 shows a conceptual block scheme of the proposed instrument integrating the optical microscope and the Raman micro-spectrometer. The folding mirror should act as an optical switch between the microscope and the Raman channels. The rugate (notch) filters will both act as beam-splitters and band rejection filters.

Starting from the sample, two channels are present: the Raman channel and the microscope one. An optical switch constituted by a simple flipping mirror separates the channels.

The objective will be common to both channels; several designs are candidate. Key issues are the selection of reflective vs dioptric systems. The main aspects to be accounted for the selection are:

i) Long working distance (to permit side illumination of the sample for microscopy).

ii) Glass and/or quartz lenses could introduce spurious Raman lines in the recorded spectra (typically around 500 cm^{-1} shift).

iii) Focusing and implementation in the optics of Raman excitation beam.

iv) Easiness of focusing (for both microscope / Raman collecting optics and Raman laser).

In a compound microscope the magnification of is given by the product of the magnifications of the objective and of the eyepiece, which in the present case is constituted by the CCD optics. Therefore, to allow the possibility of a an exploration of the sample at low magnification and a measurement at high resolution, we face again two possibilities:

i) To have two objective lenses with a mechanical 2-position switch to exchange them

ii) To have two different optical systems to couple the light into the CCD camera.

The measurement philosophy is that from the low magnification image, the science group on ground should be able to identify points of particular interest on the sample surface. After this stage, giving to the system the co-ordinates as parametric data set to perform microscopy and micro-Raman investigation only on relevant regions. This operational solution shall be compatible with the Lander operational philosophy.

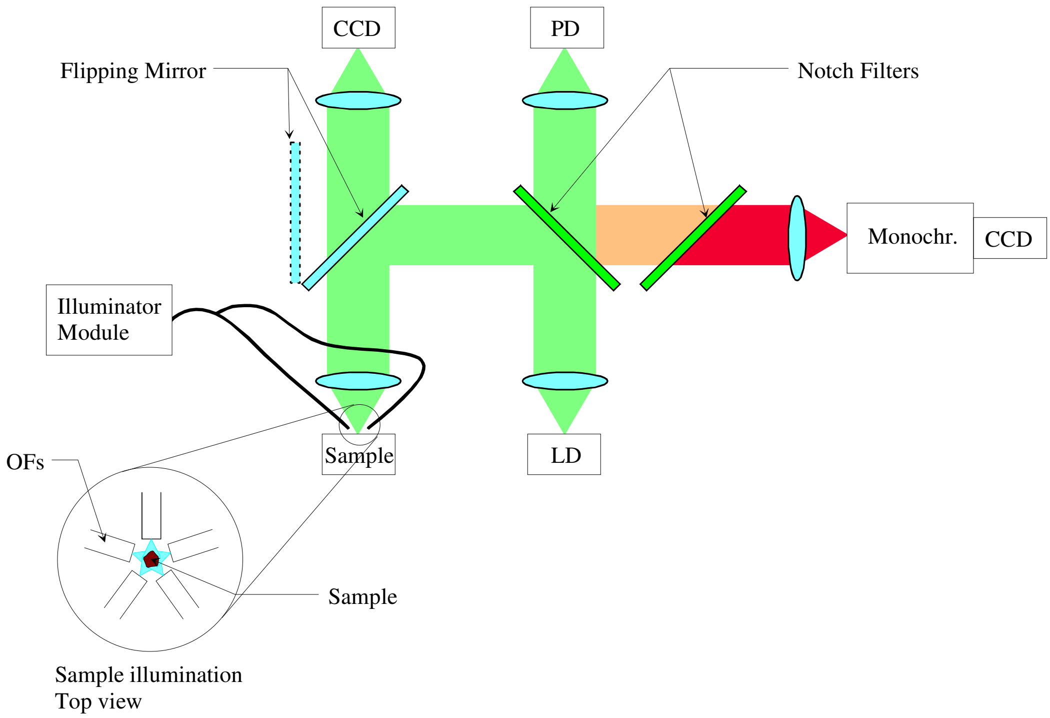


Fig.7.1.4-1. Principle block scheme of the proposed instrument.

Key element of the Raman system is the excitation source. Presently a thermally stabilised laser diode operating in the red or near IR is the envisaged element. The thermal stabilisation will be achieved by a TEC (Peltier effect) element controlled by the ECU. The laser power required will be of the order of 10÷30 mW with a total power consumption of approximately 5 W. The laser light has to be filtered since the usual line width of commercial lasers (>2nm) is too broad for Raman experiments. Furthermore, laser diodes are inherently multi-modal and mode hops are present. Since the modes have different wavelengths, the hopping causes an uncertainty in the position of the detected Raman lines. This filtering can be simply carried out by a holographic grating.

One possibility under consideration is the use of external cavity. Adding external optical cavity forces the diode laser to operate in a single longitudinal mode by creating a wavelength-dependent loss within the laser cavity. In practice, this cavity can be either a Littman-Metcalf or a Littrow design — two cavity designs widely used in dye lasers. Both of these cavities consist of a diode laser gain element with one facet antireflection (AR) coated for very low ($<10^{-4}$) reflectivity. The output from the AR-coated facet is collimated and directed onto a highly dispersive diffraction grating, In the Littrow cavity, the angle of incidence is such that the beam is diffracted back on itself. The grating therefore serves as one mirror in the cavity. In the more common Littman-Metcalf design, shown in Fig. 7.1.4-2, the grating diffracts the light toward a mirror, which reflects the desired wavelength back towards the grating and gain medium. This double-pass scheme, coupled with the grazing incidence on the grating, results in a very narrow spectral pass-band, and therefore excellent wavelength sensitivity, without the use of additional intra-cavity filters such as an etalon.

The device can be tuned by adjusting the angle of the mirror, which selects a unique diffracted wavelength. The reflected zero order from the diffraction grating has constant direction and forms the output beam. These external cavity designs yield continuous tuning over the wide gain curve of the diode laser element with a very narrow line-width. The tuning range depends on the gain element used in the cavity; at 630 nm the tuning range is 10 nm, while at 1550 nm the tuning range can be greater than 70 nm. In both cases, the line-width can be as narrow as 300 kHz. Commercial devices are available although their use in spatial activities is not assessed.

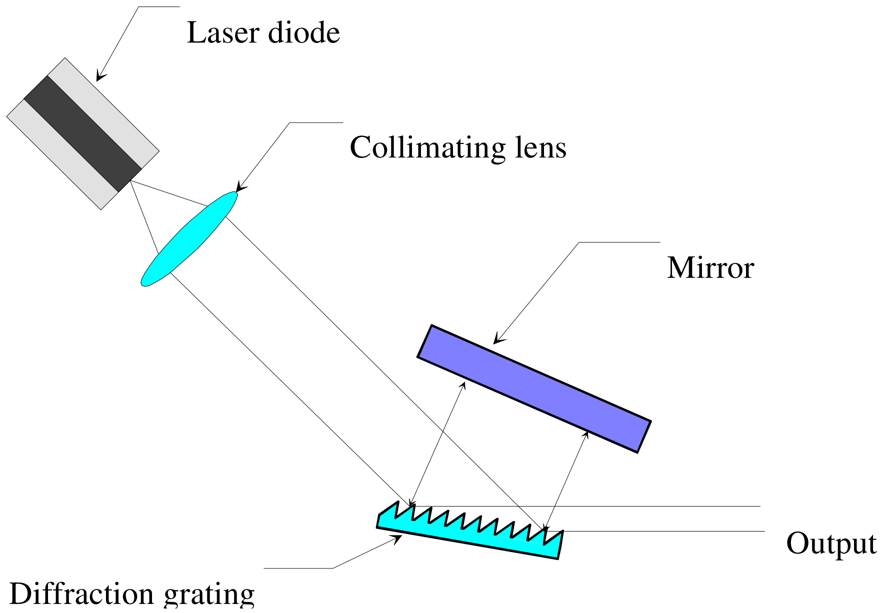


Fig. 7.1.4-2 Scheme of the Littman-Metcalf cavity.

The power budget foresees the maximum power consumption as reported in Tab.7.1.4-1.

MIRA Microscope experiment	8.9 W max
MIRA Raman experiment	10.7 W max

Tab. 7.1.4-1 MIRA Power Budget

Preliminarily assessed Mass Budget is shown in Tab.7.1.4-2.

Item	Mass (g)
Common subsystems Catadioptric optics, Optical switch, Common proximity electronics, Optical switch actuator, Housing and harness, Survival heaters	490
Microscope dedicated subsystems Microscope dedicated optics (second objectives & switch mech.), µCCD and electronics, Light source and fiber optics	340
Raman spectroscopy dedicated subsystems Laser source and thermal control, Reference photodiode, Raman dedicated optics and filters, monochromator, µCCD and electronics	520
Total	1350

Tab. 7.1.4-2 Mass budget of the proposed instrument

A case study was carried in order to evaluate the feasibility of MIRA based on a Schwarzschild objective and a Offner spectrometer. A compact implementation is shown in Fig. 7.1.4-3.

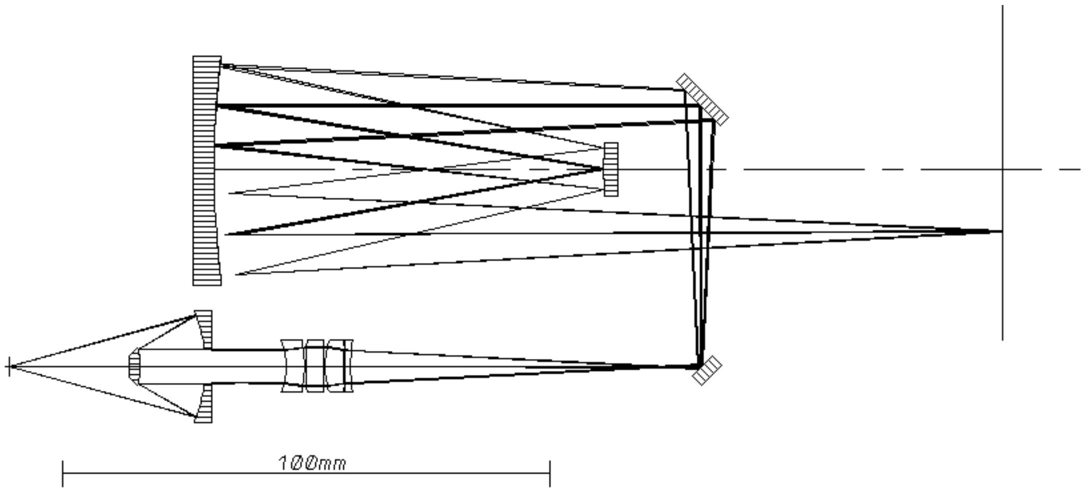


Fig. 7.1.4-3 Compact folded layout

The main conclusions from this case study are:

- The spectrometer feasibility is assessed;
- Schwarzschild objective is very effective in the spectrometer application but is not compatible with the field requested for the microscope imager;
- The dioptric solution should be investigated, although a lower working distance is expected (wrt 20 mm of Schwarzschild solution).

7.2. Physical/Chemical Analysis Instruments

7.2.1. APXS

The APXS consists of the **sensor head** and the electronics box, connected via a flex cable. The sensor head can be located separately from the **electronics box**, which must be in a thermal environment.

The Sensor Head is composed by:

- Radioactive sources and collimator
- Alpha-/Proton- and X-ray detectors
- Door / sample interface
- Pre-amplifier for the x-ray detector
- Mechanical structure
- Sample area: 37 mm dia, distance: 31 mm

The Electronics Box is composed by 5 boards (80x70mm) with the following main functions:

- Analogue signal electronics
- A/D converter
- Microcontroller
- Pre-amplifier for the detectors
- Power interface
- RS 232 interface

The resource budget is shown in Tab.7.2.1-1. The Sensor Head design is sketched in Fig. 7.2.1-1.

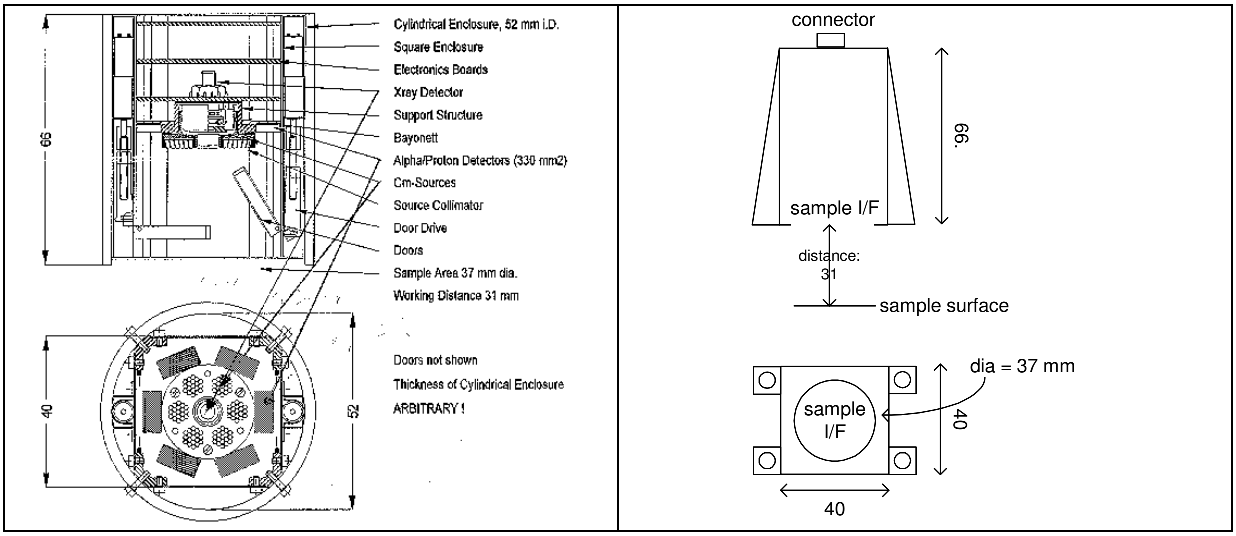


Fig. 7.2.1-1 Sensor Head Design

Sensor head	Mass	0.5 kg
	Volume	71 x 40 x 40 mm without isolation
	El. power	0.34 W, isolation thickness = 5 mm
	Thermal power*	0.1 heating (night), 0.3 W cooling (day, worst case)
Electronics box	Mass	0.5 kg
	Volume	81 x 71 x 65 mm without isolation
	El. power	5 W
	Thermal power*	0.9 W heating, isolation = 10 mm
	Data	16 bit res. x 256 channels x 3 + 16 bit x 512 channels = 20 kbit / 12 h

* thermal power required to maintain constant minimum/maximum temperature, assuming
- conductive isolation $\lambda = 0.015$ W/m/K
- radiative and convective coupling
- minimum Mars temperature (150 K) & required internal minimum temperature of the instrument, resp.
- maximum Mars temperature (283 K) & required internal maximum temperature of the instrument

Tab.7.2.1-1 APXS Resource Budget

7.2.2. Mössbauer Spectrometer

The Mössbauer spectrometer consists of the sensor head and the electronics box, connected via a flex cable harness. The sensor head can be located separately from the electronics box, which must be in a thermal environment. The sensor head is composed by:

- Drive unit
- Mössbauer sources: 300 mCi (main source, ^{57}Co), 5-15 mCi (reference), collimator
- sample interface window, mechanical structure
- 4 radiation detectors (Si-PIN diodes)
- Reference detector and calibration absorber
- Electronics boards for drive control and detectors
- Temperature sensors
- Sample area: 35 mm diameter, distance: 30 mm

The electronic box is made by:

- Instrument control unit
- RS 422 interface
- Voltage converters
- DAQ system
- Drive velocity generators
- Detector signal analysers

- Data Storage

Harness consists of 31 wires, signal lines shielded.

Sensor head	Mass	0.5 kg
	Volume	90 x 50 x 45 mm without isolation
	El. power	5W
	Thermal power*	0.4 W heating, isolation = 5 mm
Electronics box	Mass	0.5 kg
	Volume	80 x 70 x 70 mm without isolation
	El. power	5 W
	Thermal power*	1.1 W heating, isolation = 10 mm
	Data	16 bit res. x 256 channels x 3 + 16 bit x 512 channels = 20 kbit / 12 h
* thermal power required to maintain constant minimum/maximum temperature, assuming • conductive isolation λ = 0.015 W/m/K • radiative and convective coupling • min. Mars temperature (150 K) & required internal minimum temperature of the instrument • max. Mars temperature (283 K) & required internal maximum temperature of the instrument		

Tab.7.2.2-1 Mossbauer Resource Budget

The Sensor Head is sketched in Fig.7.2.2-1.

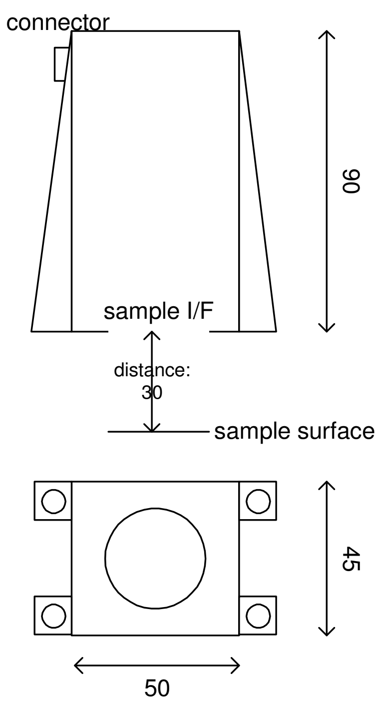


Fig.7.2.2-1 Possible configuration of the Mössbauer spectrometer sensor head on EMF

7.2.3. Atomic Force Microscope (AFM)

The candidate instrument is MIDAS (Austrian Space Research Center, Graz, PI: Dr. Riedler) to be flown in ESA Rosetta (2005) missions. MIDAS is a single instrument, located in a rectangular box. In the Rosetta mission it is designed for atmospheric dust collection on the orbiter. For EMF the sample collector wheel and the vibration damping is not required. The sample interface has to be adapted to the Sample Preparation and Handling System (SPHS) of EMF. The instrument is composed by:

- Dust collector (not required in EMF)
- Sample positioning and scanning system
- Vibration damping device (not required in EMF)
- Scanner head with sensor tips
- Electronics

The required resources are reported in Tab.7.2.3-1.

Sensor	Mass	4 kg
	Volume	200 x 200 x 150 mm without isolation
	El. power	13 W
	Thermal power*	5 W heating, isolation = 10 mm
	Data	256 x 256 pixels, 12 bit/pixel: 256 x 256 x 12 = 800 kbit / 20 min

* thermal power required to maintain constant minimum/maximum temperature, assuming
- conductive isolation $\lambda = 0.015$ W/m/K
- radiative and convective coupling
- minimum Mars temperature (150 K) & required internal minimum temperature of the instrument, resp.
- maximum Mars temperature (283 K) & required internal maximum temperature of the instrument

Tab.7.2.3-1 AFM Resource Budget

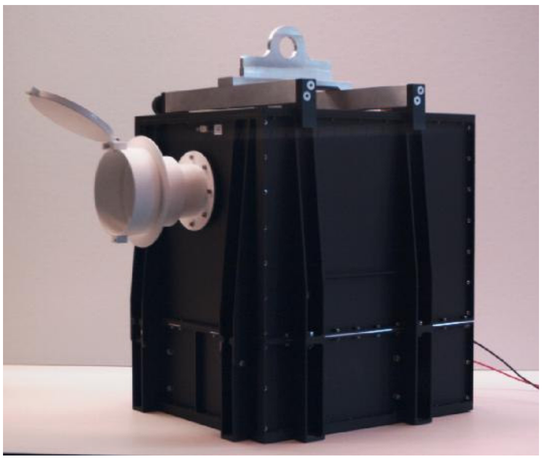


Fig.7.2.3-1 MIDAS STM (Photo courtesy: K. Torkar)

7.2.4. Oxi/GCMS

Oxi/GCMS is the acronym of Oxidant Sensor (OXS) and Pyrolysis with Gas Chromatograph (GC) and Mass Spectrometer (MS).

Requirements of Pyrolysis/GC/MS experiment are

- Quantitative and selective measurement of the oxidation state of the drilled samples
- Chemical derivatization of the drilled samples with subsequent coupled GCMS or single GC or MS
- Sample heating or Pyrolysis with subsequent GCMS or GC or MS

Requirement of the oxidant sensor is:

- Quantitative and selective measurement of the oxidation state of the drilled samples (with a strong emphasis on H_2O_2)

The proposed Technical Concept for Oxidant Sensor, that is a novel space application, is shown in Fig.7.2.4-1.

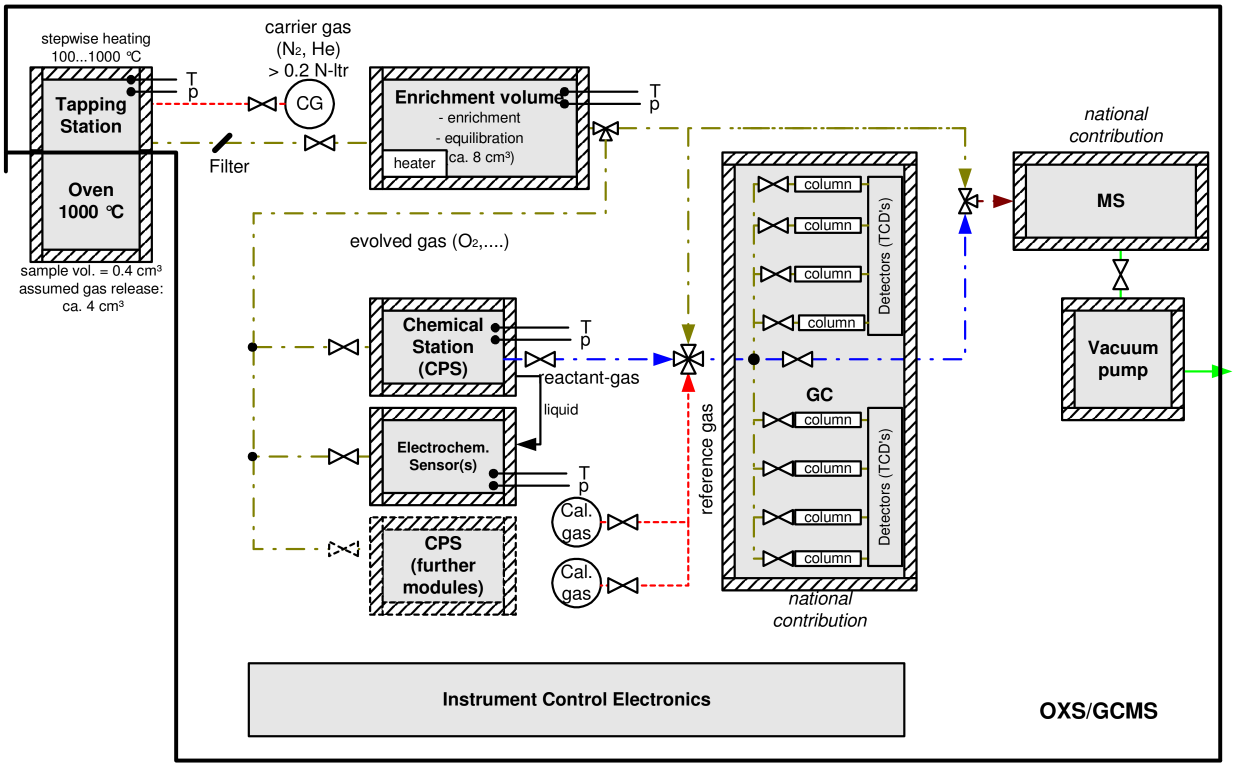


Fig.7.2.4-1 Schematic Overview of the combined OXS/GCMS Instrument

Main issues are:

- Peroxide decomposition by stepwise heating (vacuum, 100 ... 800 °C) the powdered sample of known volume;
- Quantitative gas chromatography of O_2, released from the peroxides;
- Chemical Preparation Station (CPS):
  - small modules which use as much as possible micromechanical parts (micro-mixer, -pump, -valves)
  - single use (one sample of one depth – one module)
  - wet chemistry with liquid or solid/gel reagents and gas/liquid separation, required for derivatization and selective H_2O_2 detection
  - oxidant detection with coulometric detection of O_2 (optional, not required for oxidant detection by GC)
- Linked to GCMS or GC or MS analysis, where the GC may provide some chiral columns.

Oxi/GCMS Resource Budget is shown in Tab.7.2.4-1.

Sensor	Mass	16 kg
	Volume	270 x 300 x 195 mm without isolation
	El. power	35 W (max), w/o heating power for oven
	Thermal power*	13 W heating, with oven and tapping station isolated, d=20 mm
	Data	per measurement. GC: 16 bit/65 ms/17 min= 250 kbit, MS: 16 bit * 524k/17 min =8 Mbit (data from COSAC), Chemical analysis (10 min): 7 kbit

* thermal power required to maintain constant minimum/maximum temperature, assuming
- conductive isolation $\lambda = 0.015$ W/m/K
- radiative and convective coupling
- minimum Mars temperature (150 K) & required internal minimum temperature of the instrument, resp.
- maximum Mars temperature (283 K) & required internal maximum temperature of the instrument

Tab.7.2.4-1 Oxi/GCMS Resource Budget

8. SUMMARY AND BUDGETS OF EMF

In Tab.8-1 to Tab.8-3 we report a breakdown of the EMF subsystems and the Mass and Power Budgets.

EXOBIOLOGY MULTIUSER FACILITY				
Payload Element	Mass kg	Power Watt	Heritage	Key Objectives
Sample Acquisition, Preparation, Handling System				
Drill Box (within DeeDri envelope)	9.8*	30 ÷ 100 (soil hardness)	Experience of Tecnospazio on Rosetta Comet SD2 and CNSR-SAS Study, DeeDri	Sampling depth more than 1.5m; sample dimension: ≈10 mm dia, 25 mm lenght
Manipulator (compliant to NASA '03/'05 Lander, mass could be reduced if a simpler device is considered)	10*	30	SPIDER Arm, DeeDri development	4 DOF Manipulator deploys the Drill from the Lander deck (1.7 m high) Change/adjust the position of the drill spot (X-Y) Delivers sample to handling assemblies. Brings the Drill Box in launch configuration (horizontal on the deck)
Handling Assembly 1	1.5 **	5, 30 peak	Rosetta Lander Sample Distribution System / SD2 Ovens	Carousel accommodating 12 ovens Powdering to grains less than 250 µm size Sample powdering, sealing and heating
Handling Assembly 2	2 **	5, 25 peak		Sample milling, fill the large container with sample layer
Handling Assembly 3	2.5 **	5, 30 peak		Provides flat/clean surface for observation, and positioning/scanning/focusing of sample (3DOF)

* DeeDri electronics is not included

** electronic is included in EMF electronics

Tab.8-1 EMF Breakdown and Budget (SAPH)

EXOBIOLOGY MULTIUSER FACILITY				
Payload Element	Mass kg	Power Watt	Heritage	Key Objectives
Science Instrumentation Package				
Microscope	0.25	6.6 max	Beagle II	General examination. Less than 3μm of resolution. Focus adjustment. Target for calibration control. Equipped with CCD detector. Possibility to integrate with Raman Spectrometer
Raman Spectrometer	1.5	10.8 max	Athena	Perform molecular analysis of mineral and organic (with IR optional). Spectral range: 200 to 2500 cm^{-1}. Spectral resolution: $8cm^{-1}$.
Infrared Spectrometer (2nd priority)	1.4	12 max	IRMA (VIRTIS in Rosetta)	Perform analysis of mineral and inorganic. Wavelength range: 0.8÷5μm. Spectral resolution: >100λ/Δ. Spatial resolution: 40μm.
APX Spectrometer.	1	5.5	APXS (Athena)	Determine quantitatively all elements, except H and He. In particular it is able to analyse carbon down to 0.1%.
Mossbauer Spectrometer	1	10	MIMOS II (APEX)	Perform analysis of minerals and iron compounds, in particular the oxidation state of iron directly.
OxiGCMS	16	65 (peak) 35 (average)	COSAC (Rosetta Lander)	Determine isotopic, elemental, organic and inorganic molecular composition, and chirality measurement. Measurement of oxidants (H_2O_2, O_2, O_3) in the soils and their concentration gradient with depth.
AFM (2nd priority)	4	13	MIDAS (Rosetta)	Atomic and molecular analysis

Remark: An integrated solution Optical Microscope + Raman Spectrometer is presented as option.

Tab.8-2 EMF Breakdown and Budget (Instrument Package)

Payload Element	Mass kg	Power Watt	Heritage	Key Objectives
Service Module				
Electronics (includes Drill and Manipulator one)	6	18 max (excluded power for actuators)	OG experience on GOME, VIRTIS, FAST, Mars '03	Power Supply conditioning and distribution to all electrical/electronics Subassemblies, the electronic control of the overall operations, the communications between Control Unit and the Instruments and Data Handling and the Lander. Structure (box) can be reduced if electronic boards will be located inside the Lander.
Mechanical Structure	5÷10	-----	OG experience on GOME, VIRTIS, FAST Mars '03	Holds the various equipment; provides the interface to the Lander, provides thermal insulation. Presently three blocks are foreseen, for each sample preparation / instrumental groups.
Harness	1.5	-----		Rough estimate
Thermal Insulation	3.5	----	OG experience on GOME, VIRTIS, Mars '03	It is part of EMF thermal conditioning, taking into account the Mars environmental temperature and the I/F with the Lander. Provides also some protection from surrounding dust. It is defined by the available power for EMF heating (survival, up to switch-on phase).
Thermal control	0.5	10 W	OG experience on GOME, VIRTIS, Mars '03	Provides thermal conditioning of EMF equipment during operational phase. It is assumed that the Lander directly manages survival heating.

Remark: EMF EQUIPMENT will not be operated at the same time, therefore the power consumption is depending on the actual operation; the sequencing can be properly defined to minimise the overall power need.

Tab.8-3 EMF Breakdown and Budget (Service Module)

The mass budget has been summarised in Tab.8-4.

Item	mass estimate	remark
Handling Subsystem	6 kg	
Electronics (all S/Ss)	6 kg	
1st priority Instruments	19.7 kg	
2nd priority Instruments	5.4 kg	
Drill	9.8 kg	
Manipulator	10 kg	NASA '03 Arm (1.7m)
Mechanical Structure	10 kg	worst case estimate
Harness	1.5 kg	
Thermal Insulation	3.5 kg	1 sqm Aerogel
Thermal control	0.5 kg	
total	**72.4 kg**	**52.6 kg w/o drill & manipulator**

Tab.8-4 EMF Summary of mass Budget

We'd like to remark that the estimated mass figure should be considered as a worst case evaluation. The Manipulator arm has been dimensioned as per NASA '03/'05 mission, where the distance from Lander deck to soil surface is 1.7 m. A simplified manipulator can be envisaged in case of a smaller lander. Regarding the structural frame, a rough estimate has been made; a deeper analysis requires a frozen configuration and the knowledge of the mechanical interfaces with the lander, the level of integration with it and the required static / dynamic loads that the system should withstand.

9. LIST OF ACRONYMS AND ABBREVIATIONS.

AFM	Atomic Force Microscope
AO	Announcement of Opportunity
AP	Additional Payload
APXS	Alpha/Proton/X-ray Spectrometer
ASI	Italian Space Agency
bps	bit per second
CCD	Charge Coupled Device
DeeDri	NASA MSR '03/'05 Deep Driller
DOF	Degree of Freedom
EMF	Multi-User Exobiology Facility
ESA	European Space Agency
ESE	Experiment Support Equipment
GC	Gas Chromatography
HEDS	Human Exploration and Development of Space
JPL	Jet Propulsion Laboratory
LED	Light Emitting Diode
MS	Mass Spectrometer
MAV	Mars Ascent Vehicle
MoM	Minute of Meeting
MSP	Mars Surveyor Program
MSR	Mars Sample Return
NASA	National Aeronautics and Space Administration
OG	Officine Galileo
PCD	Poly Crystalline Diamond
PI	Principal Investigator
PIP	Proposal Information Package
QM	Qualification Model
RHU	Radioisotope Heating Unit
SAPH	Sample Acquisition Preparation and Handling (Sub System)
SPHS	Sample Preparation and Handling Sub System
SD2	Sample Drilling and Delivery (System on Rosetta Payload)
SOW	Statement of Work
TBD	To Be Defined
TEC	Thermo-Electric Cooler
TLC	Telecommunications
vs	versus
WBS	Work Breakdown Structure

❑